METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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METALLURGIA

THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER."

MAY, 1945 VOL. XXXII. No. 187

Victory !

THIS month will be an outstanding one in world history and in British history in particular. It will record the complete subjugation of the German armed forces and the dissolution of the Nazi regime. Many realised that victory in the field was near, but few in Britain expected Germany's collapse would come so suddenly and completely. It is not surprising, therefore, that the British people were staggered by the good news.

History will record that for about a year Britain, with the able support of her partners in the British Commonwealth and of her Colonies and India, carried on the fight alone. Against great odds both in men and weight of armour her people bore the brunt of enemy attacks with a casualness that was an inspiration to other friendly nations. But, under the leadership of Mr. Churchill, to whom no tribute adequately expresses the feelings of the British people, what at one time seemed a forlorn hope gradually developed, with resolution and steadfastness, into a powerful force, which, ultimately, has been largely responsible for the defeat of the enemy.

It is not proposed to attempt to pay tribute to the many who have contributed to this great victory, it would be an impossible task, but in any unbiased tribute a very high position would be accorded to the British people who stood firm when all seemed lost. Now that the tumult and shouting has subsided, let us briefly review the objectives for which Britain declared war on Germany and for which the Allied Nations are still fighting. In our September, 1939 issue, on the outbreak of war, we said " before the heat of the struggle interferes with our vision it is worth while to record the goal for which Britain and her Allies strive. No dynastic ends are sought, no territorial changes, no gold and no new supplies of raw materials. It is not the spoils of war that this country and Empire seek to win. We are fighting for something fundamental that is beyond human valuation : we are fighting to defend moral values—liberty, good faith between men and nations, justice to strong and weak alike, the pledged word, and the common decencies of what we regard as essential in civilised countries." That these objectives remain is indicated by Mr. Churchill's closing words in his call to the British people for a final effort : " Forward, unflinching, unswerving, indomitable till the whole task is done and the whole world is safe and clean." Indeed, it is probable that the indomitable spirit already shown by the British people arose from the feeling that these values should not be allowed to perish.

This victory, however, can only be regarded as the completion of an important stage in the movement towards the establishment of a world order of free peoples. The use of armed force must continue until Japan too is overcome and the Pacific peoples at present enslaved to the Japanese are set free. Britain can be relied upon to supply an ever-increasing contribution to this effort. While there is much to be done before this unscrupulous enemy to mankind is subdued, the maintenance of the same mutual understanding and team-work that has been so successful against the Germans will assist greatly in subjugating Japan and speedily bring welcome relief to China.

With the cessation of armed warfare, whether in Europe or the Far East, the objectives of the Allied Nations will become more difficult of attainment and the same degree of mutual understanding and teamwork must be displayed to achieve success. There is ample evidence of this in Europe where war has disrupted the whole machinery of civilisation and brought communities and even nations to a condition bordering on starvation level. The progress of the liberated European countries, and even of Germany, is dependent upon reconstruction, but this gigantic task cannot be undertaken unless the liberated peoples are adequately nourished. The task before the United Nations seems to be an impossible one.

The most drastic shortages in food for supply to these countries from British, Canadian and United States sources, notably of meat, sugar, rice, fats and oils, will probably extend well into 1946. But the most urgent problem facing the United Nations is one of distribution : how to supply sufficient food to tide over immediate difficulties. The principal distribution snags include shortage of shipping, the disruption of transport in European countries within the war area and the run-down state of agriculture in some of those that are most densely populated. Actual means of overcoming these snags have yet to be devised in detail, but by the closest co-operation between all nations it is claimed that the job can and will be done. That is the spirit in which these and other difficulties in the liberated countries are being tackled.

Thus, when we rejoice and feel proud, as we should, let us realise that our objectives are only partially achieved. We must cement good will and nothing surely can more thoroughly cement post-war amity between nations than ready expressions of good will through practical and immediate assistance. Britain can do little herself but the response from food exporting countries throughout the world has been great. Even in this country further sacrifices will be cheerfully borne by those who can imagine the feelings of hundreds of thousands of hungry Hollanders in The Hague, Rotterdam

The fact that goods made of raw materials in short supply owing to war conditions are advertised in " Metallurgia " should not be taken as an indication that they are necessarily available for export.

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and Leyden when "food bombs" rained on them from the skies; literally "manna from heaven," their first adequate food supplies for many months.

Reconstruction at home must proceed as fast as possible, but let us commence to attack its problems gradually, so that it will proceed with ever increasing momentum, through mutual understanding and teamwork, keeping in mind that the complete victory we seek will only be achieved when moral values—liberty, good faith between men and nations, justice to strong and weak alike, the pledged word, and the common decencies of what we regard as essential in civilised countries—predominate and selfish interests are relegated to the background.

Light Metals in the Shipbuilding Industry

CONSIDERABLE progress had been made in the application of aluminium alloys in shipbuilding and marine engineering before the war, it is not surprising, therefore, that attention is being given to possible expansion of their use in these fields after the war. As with road and rail transport, efforts will be made to reduce the deadweight of vessels, in order to effect economy in power consumption or to increase the profitable cargo to be carried. Since an aluminium alloy is, for an equal volume, about one-third the weight of ferrous alloys, the earning capacity of a ship in which aluminium has been liberally used can be considerably increased. After-war competition, especially with passenger ships, will emphasise the desirability of reducing the deadweight of a vessel, either to permit greater speed for the same power and fuel cost, or the same speed at lower power and fuel cost. To some extent magnesium alloys are also concerned in this development.

Probably the greater possibilities for the use of light metal alloys are their application for deck-houses, ventilation and deck engine casings. Aluminium alloys have already been used for lifeboats and the substantial reduction in their weight permit the lightening of davits, winches and pulling gear necessary for lowering them into the sea, thus effecting a cumulative saving in weight. Alloys of the aluminium-magnesium type would do admirably for cabin bulkheads and furnishings and would greatly reduce the fire hazard present when timber is used.

On the question of maintenance, aluminium alloys offer distinct advantages, as certain alloys offer good resistance to sea-water corrosion and the maintenance costs are relatively low. As cost is generally regarded as a serious obstacle to the more common use of aluminium in this field, the question of maintenance has a bearing on the initial outlay in applying aluminium alloys.

It is noteworthy that Mr. Henry J. Kaiser, in a statement before a recent meeting of the U.S. Senate's Small Business Committee, commented on the post-war use of magnesium and aluminium in the construction of naval and merchant ships. Pointing out that these metals had not been used extensively in ship construction before the war, he told the Committee that negotiations for the building of a destroyer wholly of aluminium had been completed the day before the Japanese attack on Pearl Harbour. The plans were deferred because of the paramount need of aluminium for aircraft. That aluminium destroyer, said Mr. Kaiser, would have been capable of travelling at 60 knots and of turning on a very short radius. Some day it will be built, and, if expectations are correct, many of the fighting ships now in service may be rendered obsolete.

Continuing Mr. Kaiser said the use of the two light metals in the superstructure of merchant ships designed for post-war passenger service would afford many advantages and that design changes for the use of the metals in ship construction were now being studied by the U.S. Maritime Commission. He also forecast a widespread use of magnesium and aluminium for the shipment of freight in demountable containers that could easily be shifted from railway wagons and lorries to ships.

In cargo vessels, owners are naturally interested in the question of capacity. Obviously, much depends upon the nature of the cargo to be carried, but, while the reduction of a vessel's deadweight by using aluminium will permit the live load to be increased by the amount of deadweight saved, the capacity would remain the same, unless the vessel is specially designed to take full advantage of the benefits resulting from the employment of aluminium.

Award of the Bessemer Gold Medal

THE Bessemer Gold Medal, which is the highest award of the Iron and Steel Institute, has been awarded to Mr. Harold Wright, chief metallurgist to Dorman Long & Co. Ltd., Middlesbrough, in recognition of his valuable contributions made over many years to improve the technique of iron and steel manufacture. The presentation will be made at the annual meeting of the Iron and Steel Institute to be held in London on May 9.

Mr. Harold Wright has been a member of the Institute since 1902, has served on the Council of that body, is a member of a number of technical committees concerned with the industry, and a past-president of the Cleveland Scientific and Technical Institution and of the Cleveland Institution of Engineers. He started work at the North Eastern Steel Works under Mr. C. H. Ridsdale, later joining Mr. E. H. Saniter, afterwards a Bessemer Gold Medallist. Mr. Wright attended classes under Dr. J. E. Stead, also a Bessemer Gold Medallist. While with Sir Bernard Samuelson, Mr. Wright took an active part in the supply of molten basic iron to Dorman Long's Britannia Works when the latter firm introduced the hot metal process 40 years ago. While in charge of the Newport coke ovens he pioneered the use of coke oven gas for town purposes. He first made the suggestion in 1902, but it was 1913 when supply was established.

Mr. Harold Wright also possesses considerable geological knowledge and has done a great deal of exploration work in connection with the Cleveland Ironstone deposits. He was also responsible for the introduction into local blast-furnace practice of the use of rich foreign ores in the Cleveland burden. He was appointed chief metallurgist to Dorman Long & Co. Ltd. in 1918. Last December the Company inaugurated a triennial Harold Wright Lecture to be given before the Cleveland Scientific and Technical Institution in recognition of his long and valuable service.

"Lead Printing" Ferrous and Non-Ferrous Metals

By W. B. Wragge

The introduction of small percentages of lead in many steels to improve their machining properties has increased the need for developing a method of lead printing in order that the distribution of the lead can be examined. A number of methods, in which several solutions are used, have been developed, but the simple technique described in this communication employs a dilute caustic soda solution which not only gives satisfactory prints of lead in lead bearing steels but is also applicable to non-ferrous metals.

THE earliest published method of examining the distribution of lead in a metal by a process now known as lead-printing, and similar in general principle to sulphur printing, appeared in *Aluminium* in 1938. The solvent used was 95 per cent. acetic acid and the moistened medium, filter paper, applied to an aluminium specimen containing lead. The print was developed by treatment with H_2S or Na_2S solution Later a method for lead printing steel specimens appeared in the *Analyst*,* employing 50 per cent. acetic acid and chemically converting into a dithizone lake, the lead salts being absorbed into de-silvered gelatinised paper. The writer, having found that the use of ammonium acetate solutions, both slightly acid with acetic acid and also slightly alkaline with ammonia, to steel samples, gave relatively successful results, found it necessary to remove iron stains by further chemical treatment. The employment of dilute caustic soda solutions, however, eliminates all iron staining and resulted in the following simple technique :—

Materials

Solution.—5% caustic soda solution in water.

Developing solution.—5% sodium sulphide solution, freshly made.

Paper employed.—The choice is wide. For lead prints of the finest definition de-silvered matt surfaced printing paper is quite suitable ; alternatively a toughened fine grained filter paper, such as Whatman 50, or very smooth surfaced white blotting paper, gelatinised as indicated, are eminently suitable.

Gelatinising plain papers.—Sheets are immersed in 5% gelatine solution in water at 35° C. and subsequently drained and hung up to dry. This gelatinised paper may be hardened in a 2% formalin solution if considered desirable.

Procedure

For steel samples, file the flat surface of the specimen, or in the case of fine sawn or milled surfaces, it is sufficient to etch the surface with a 10% solution of ammonium persulphate to obtain a gray etching effect. For non-ferrous materials, in which the lead content is relatively high, best results are obtained, after preparing a flat surface on the specimen by milling, fine sawing or filing, by etching the surface with a suitable etchant to produce a desired macro etch. For example, HNO_3, S.G. 1·2, or a 50% ammonia solution.

The printing paper is immersed in the caustic soda solution for sufficient time to saturate, say, about 2 mins., *lightly* dried between blotting paper, and placed into intimate contact with the metal surface by thumbing or by the use of a soft squeegee, in order to produce intimate contact over a whole area of the surface and to exclude air bubbles.

The optimum contact time, both for steel and brass, appears to be about 2 mins., after which the paper is stripped from the specimen and developed in the sodium sulphide solution. Development only takes a few seconds.

In the case of steel specimens a short wash in running water, say 10–15 mins., is all that is required before drying the prints. With copper alloys, the slight brown stain resulting from a little pick-up of copper is removed by immersing the paper, after the print has been developed, in a 10% potassium cyanide solution for about 15 secs., followed by water washing and drying in the usual manner.

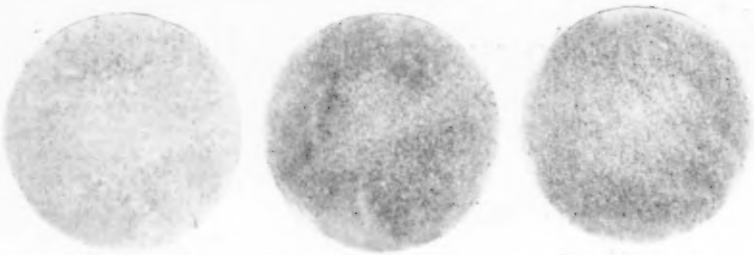
Experimental Results

In order to determine the most suitable concentration of caustic soda for the purpose, tests were carried out using solutions with increasing caustic soda content. Fig. 1 shows the results obtained on a sample of steel having a lead content of 0·20% and using 1%, 5% and 10% caustic soda solutions respectively, to produce the standard lead prints A, B and C.

The lead prints reproduced in Fig. 2 form part of a series of tests made on samples of steel with an increasing lead content. The lead content of the specimens ranged from 0 to 0·30% and the prints were produced by the method described on gelatinised Ford 438 Mill blotting paper. In addition to the prints reproduced in A, B, C and D of Fig. 2, prints were made from a sample containing no lead and from another containing 0·05% lead. In the former no discoloration took place, while in the latter the presence of even this small percentage of lead is discernible, although not easily reproduced as an illustration. The examples shown, however, indicate the increasing intensity of stain with the increasing lead content of the steel specimens.

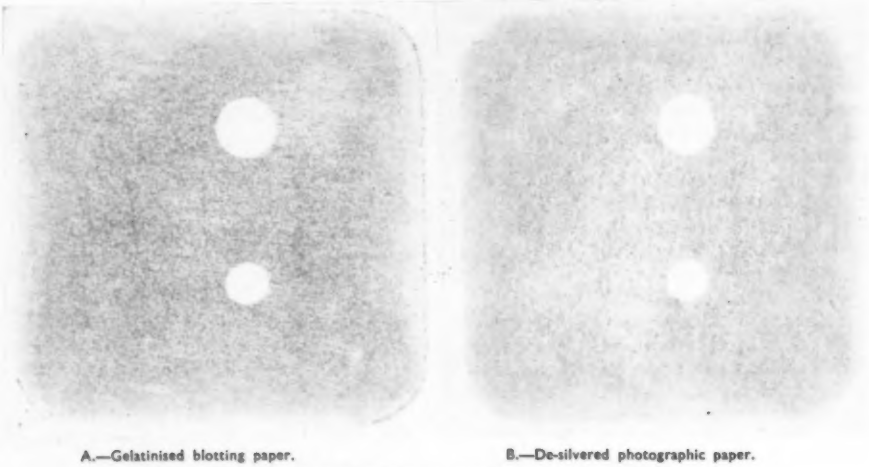
The distribution of lead in a normal lead-bearing steel billet sample is shown in Fig. 3, while Fig. 4 shows segregation of lead in a billet taken from the normal discarded portion of a leaded steel ingot. The prints marked A in each of these illustrations were made on gelatinised toughened fine grained filter paper, while those marked B were made on de-silvered matt surfaced photographic printing paper. The two white circles in the uniform lead prints of Fig. 3 are the result obtained

* December, 1944.



A.—1% Caustic soda. B.—5% Caustic soda. C.—10% Caustic soda.

Fig. 1.—Standard lead prints of a steel sample containing 0·20% lead using caustic soda solutions of different strengths.

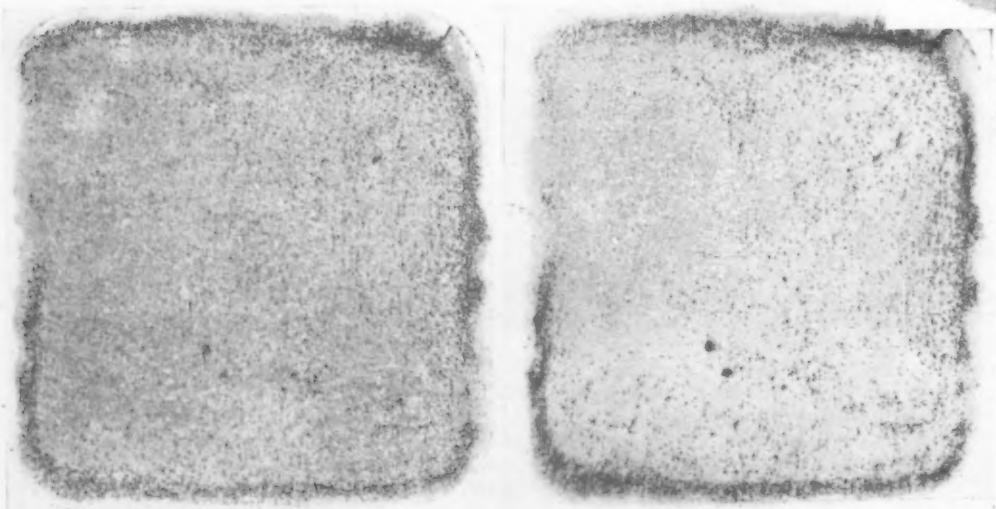


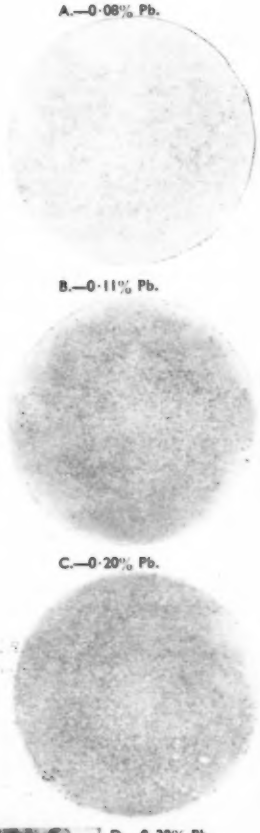
A.—Gelatinised blotting paper. B.—De-silvered photographic paper.

Fig. 3.—Showing the distribution of lead in a normal steel billet. Two lead-free steel plugs were introduced in the sample, and as will be noted, the interface between lead-bearing and lead-free steel is well defined.

Fig. 4.—Showing the lead segregation in a billet taken from the normal discarded portion of a leaded steel ingot.

A.—Gelatinised blotting paper. B.—De-silvered photographic paper.





A.—0·08% Pb.

B.—0·11% Pb.

C.—0·20% Pb.

D.—0·30% Pb.

Fig. 2.—Standard lead prints of steel samples, with gradually increasing lead content, using gelatinised Ford 438 Mill blotting Paper.

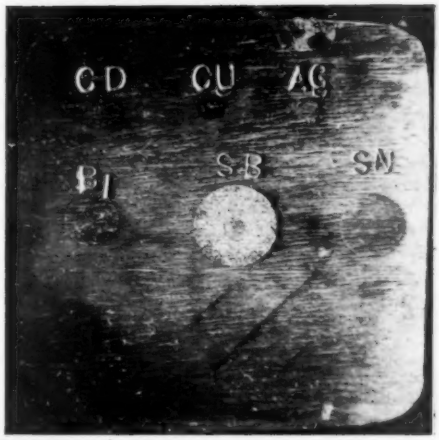
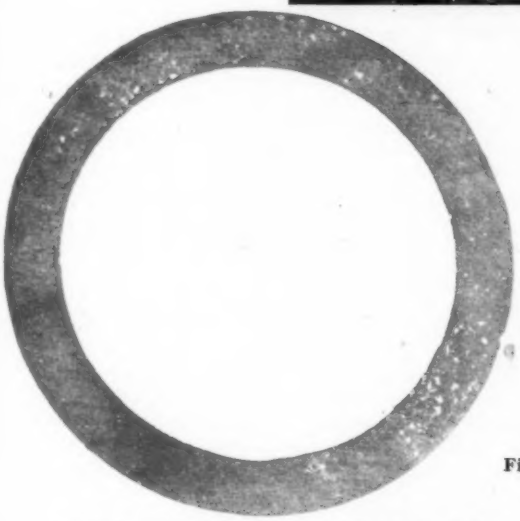
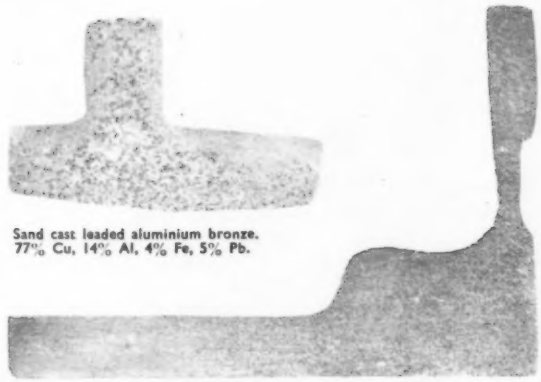


Fig. 5 (Left).—Photo-macrograph of a lead-free mild steel billet plugged with cadmium, copper, silver, bismuth, antimony and tin. (Right).—Standard lead print of the same specimen to show the influence of the various metals.



Centrifugal casting of leaded bronze. 80% Cu, 15% Sn, 5% Pb.

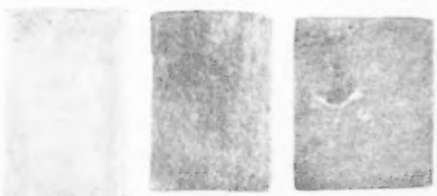


Sand cast leaded aluminium bronze. 77% Cu, 14% Al, 4% Fe, 5% Pb.

Sand cast gun metal. BSS. 1024. 2% Pb.

Fig. 6.—Standard lead prints of some copper alloys made on gelatinised Whatman No. 50 filter paper.

(All these samples were supplied by J. Stone & Co., Ltd.



Brass with 1% Pb. Brass with 2·5% Pb. Phosphor bronze with 3% Pb.

Fig. 7.—Standard prints of copper alloys showing increasing lead contents.

from the introduction into the steel billet of two lead-free steel plugs, one being a sample of free-cutting quality steel, and the other a 0·40% carbon grade. These indicate the absence of iron staining and the sharpness of definition at the lead-bearing and lead-free steel interface.

The effect of interference from other metals was studied by preparing a steel billet with inserts of cadmium, copper, silver, bismuth, antimony and tin. A photo-macrograph of this mild steel billet is shown at A, Fig. 5. The lead print of this composite billet, reproduced at B, Fig. 5, indicates that tin gives a brown stain, and bismuth a very light brown stain ; both tin and bismuth stains

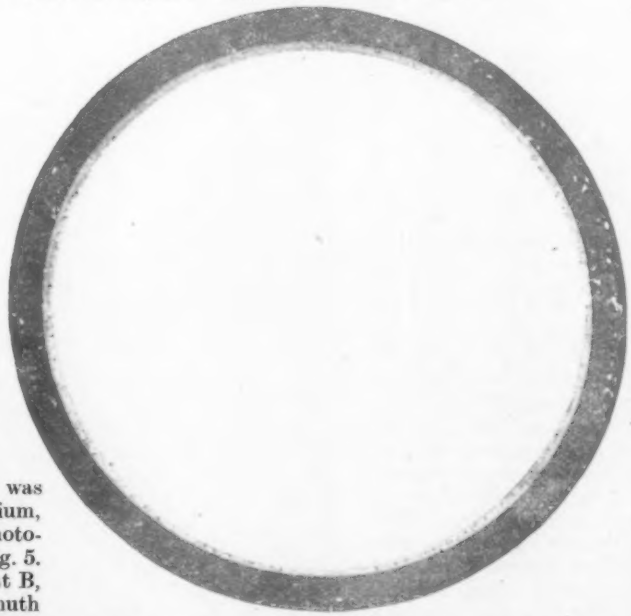


Fig. 8.—Leaded copper alloy surrounding a standard grade of lead-bearing steel.

are removed in the cyanide clearing solution referred to previously. The stain resulting from the tin was found to fade fairly rapidly, presumably due to oxidation effect.

The use of the caustic soda method of lead printing was studied in its application to some copper alloys. In the first place prints were made from specimens of lead-free copper and bronze. In both instances a very slight brown stain was produced, but was removed in a few seconds with the cyanide solution treatment. It is noteworthy that the tin in solution in the bronze did not interfere with the print. A number of lead prints from miscellaneous lead-bearing non-ferrous metals is given in Fig. 6. It is interesting to note that the sand-cast specimens have sufficient definition to indicate the dendritic cast structure, and that etching leaded aluminium bronze and centrifugally cast leaded bronze somewhat reduces the overall intensity of the print, and lightens the background.

That the intensity of the stain produced on the print increases with the lead content is clearly shown in Fig. 7, which reproduces prints taken of (*a*) a brass containing 1% lead, (*b*) a brass containing 2·5% lead, and (*c*) a leaded phosphor bronze containing 3% lead. The lead print reproduced in Fig. 8 is noteworthy in this respect, the specimen comprised a leaded copper alloy surrounding a standard grade of lead-bearing steel.

Spot Testing

This caustic soda technique of printing can be usefully applied for spot testing metals containing free lead by the following simple method. Apply one or two drops of 5% caustic soda solution to a roughly filed surface of the metal to be tested. After one minute pick up the solution with the corner of a piece of white blotting or filter paper. Apply the sodium sulphide developing solution by placing a drop from a glass rod behind the corner of the filter or blotting paper. A brown stain positively indicates lead. The stain produced with lead-free copper alloys is very slight indeed and cannot be confused with the deep stain resulting from the presence of lead in such alloys. Lead-free steel, of course, gives no stain at all, with a brown stain in the case of lead-bearing steel.

Keeping Lead Prints

In conclusion, it is worth recording that lead prints, produced by the method described, will keep indefinitely in envelopes or folders, but tend to fade slowly on continued-exposure, for example, in the case of laboratory atmospheres. A more recent development has been the use of cellophane sheet for lead printing, the resultant print acting as an excellent photographic negative or as a lantern slide. Cellophane is particularly easy to manipulate and to apply to the surface of the specimen.

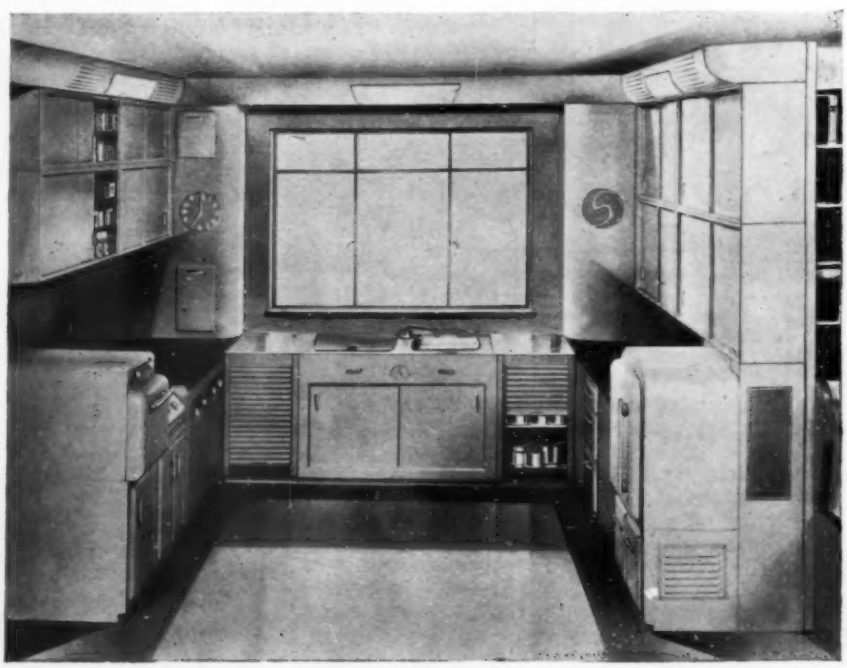
The author wishes to express his thanks to those firms who kindly provided samples of lead-bearing non-ferrous metals, to Mr. Pryce for the preparation of prints, and to Ledloy, Ltd., for permission to publish this communication.

Aluminium Kitchen

WHAT is believed to be the first planned kitchen designed specifically to be built in aluminium is shown in the accompanying illustration. It is designed by Mr. Ernest R. Gilbert, of 10, Norfolk Street, W.C.2 The considerations that led to the choice of aluminium and its alloys as the ideal material for the kitchen are interesting. They include availability, workability, appearance, non-toxic quality and low upkeep cost. Psychologically, too, it is sound to jacket the kitchen appliances with a metal the housewife already knows and likes.

The "Gilbert" kitchen has been designed and planned in standard size units and with an eye to assembly line production. The wall cupboard units, for instance, have sliding doors designed in a simple one-piece pressing, with a recessed handle and roller-inserts. They slide easily, cannot warp and are dust-proof and pest-proof and ideal for food storage.

It is built up in standard sized units which include a two-unit cooker, a washing machine, a dish-washing machine, with a waste disposal unit, a refrigerator, clothes drying chamber, work bench, and a full range of cupboarding.



Blackheart Malleable Iron Castings used on New Sydney Graving Dock

It is well known that where strength, ductility, machinability and resistance to shock are important considerations, malleable iron castings find a wide field of industrial applications. There has been a tendency, however, to limit the size of castings of this type, but production methods developed in recent years have greatly increased the size of malleable castings as is indicated by this description of the application of Blackheart malleable cast iron to the production of large and heavy castings.

MOST readers familiar with the use of malleable cast iron generally think of castings in this material weighing anything from a fraction of an ounce to a few pounds, with an exceptional heavy casting on very rare occasions. This idea that malleable production is confined only to small castings is reminiscent of the days when nothing more important than harness furniture and the like was made in this material. Actually, blackheart malleable cast iron has been developed to such an extent that it ranks in competition with steel, and continues to make progress in the "heavy casting" field.

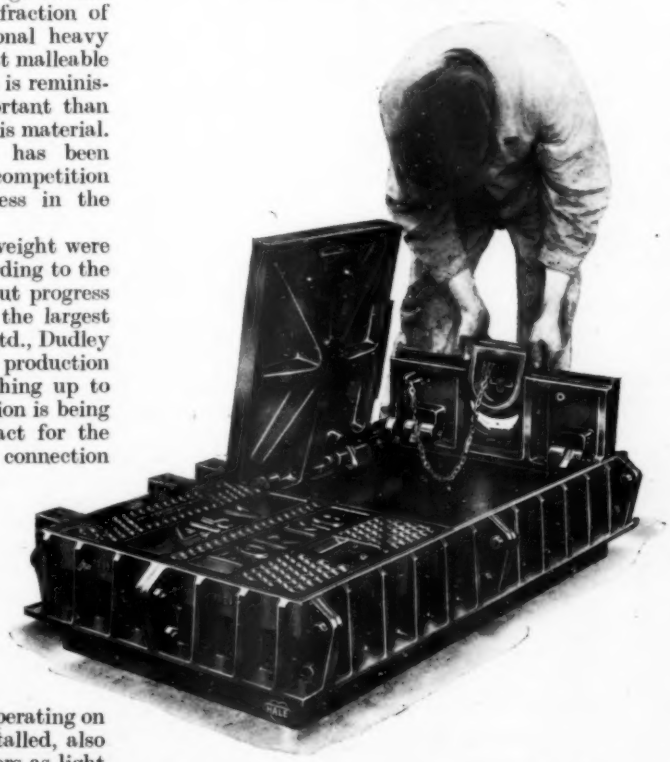
Formerly castings in excess of 112 lb. in weight were generally produced in cast iron or steel according to the class of job for which they were required, but progress in recent years has been such that one of the largest Midland founders, Hale and Hale (Tipton), Ltd., Dudley Port, Staffordshire, has been developing the production of large blackheart malleable castings weighing up to 250 lb. each. Their experience in this direction is being applied to the execution of a secial contract for the Commonwealth Government of Australia in connection with an important Naval installation at Sydney, N.S.W.

The contract covered the supplying and fitting of about 50–60 tons of heavy-duty manhole frames and covers of a type generally called for in cast iron. In the opinion of the consulting engineers ordinary cast iron was unsuitable for the job. This was due to the fact that the cast covers were required to withstand a test load of 10 tons to allow for the mobile cranes operating on the dock yard where the manholes were installed, also it was desired to keep the weight of the covers as light as possible. The cranes had to be free to pass over the manholes without fear of breaking through and damaging vital control gear below. Another aspect was that unauthorised persons should be prevented from easily gaining access to the manholes. The construction of these manhole frames and covers will be appreciated from the illustration given in Fig. 1.

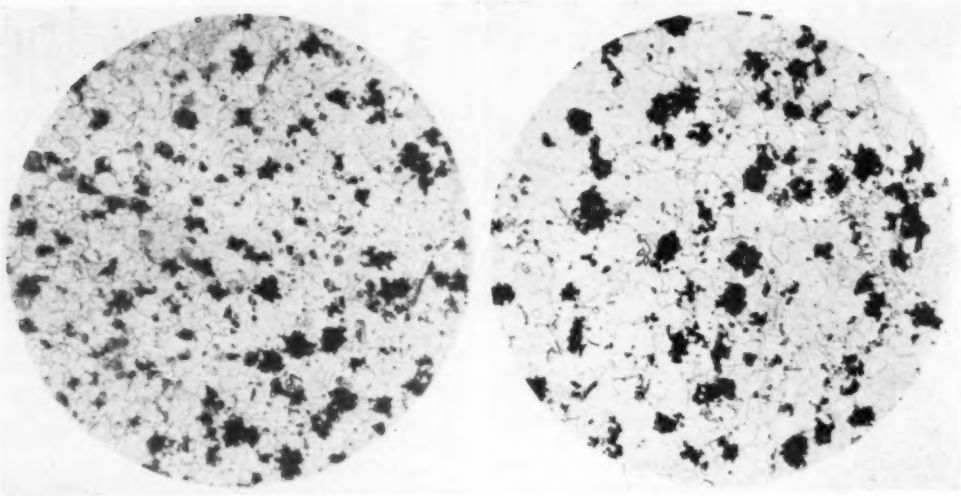
The original intention was for the work to be carried out in the Commonwealth but, apparently, facilities were not available. Difficulty was, no doubt, experienced in finding a local founder capable of producing malleable iron castings to the size and weight required, as some of the assemblies weighed over half a ton each. The work was finally undertaken by Hale and Hale (Tipton), Ltd., who are specialists in the production of blackheart malleable iron castings.

The main problem was, firstly, to produce heavy manhole frames, measuring 5 ft. to 6 ft. in length × 2 ft. to 3 ft. wide, to conform reasonably to dimensions when annealed. Secondly, the frames had to accommodate heavy malleable cast iron doors measuring 2 ft. to 3 ft. square, weighing anything from 200 lb. to 250 lb. each. In ordinary cast iron these points would not present any major difficulty, but when working in malleable, factors of variable contraction, expansion and warping during annealing had to be considered.

Fig. 1.—General arrangement of the manholes, frames and covers.



The conditions of the contract specified a high quality of equipment, only the best workmanship and materials were acceptable. It was the consulting engineers' desire to prove to the world that British workmanship retained its high standard even in the midst of the present conflict. No second best was accepted and specifications had to be rigidly adhered to. When assembled, the covers required to be entirely free from rock, flush fitting and with as little clearance as possible between frame and cover.



A.—Section 2 × 7 in. B.—Centre of section 2½ × 2½ in.

Fig. 2.—Photomicrographs taken at different sections of the same casting. × 50. Note the similarity of the temper carbon.

The difficulty of growth and distortion was overcome by producing the frames in suitable sections and machining joint faces to give perfect fitting and finish. The heavy doors and covers were produced after preliminary trials for expansion and, after annealing, were fitted to the frames with little or no adjustment apart from a hand-buffing operation on the small chipping strips to eliminate any rock that may be caused by annealing distortion. It is a common belief that such large castings as these under consideration cannot be dimensionally controlled when produced in malleable, but the manufacturers report that results in this respect were most satisfactory.

Apart from strength, it was necessary for the castings to be clean and neat in finish. Each cover required to be marked in easily decipherable characters and, as will be noted in Fig. 1, the reader will appreciate that the finish of the malleable covers is equal to that obtained in grey cast iron. All hinges were fitted with steel pins and sectionised brass bushes and wrought iron hinges to reduce corrosion by sea-water.

Metallurgical Aspect

Viewing this work from the metallurgical aspect, the reader will quickly appreciate, from a study of the photomicrographs, A and B, taken at two typical thick sections and shown in Fig. 2, that a first-class "blackheart" structure has been maintained.

The photomicrographs, which are taken at a magnification of 50, illustrate the general structure of two typical sections found in one of the castings. As is well known one of the essential precautions in the production of metallurgically sound blackheart malleable castings is to ensure against the presence of primary graphite in the hard iron prior to annealing treatment. This type of graphite persists during annealing and has a serious detrimental effect upon the strength and ductility of the material. Unless the metal composition is correctly balanced to give a completely white iron throughout the whole of large castings, it is possible to have metal free from primary graphite in lighter sections, and mottled or even grey in the portions where the more massive sections appear. Therefore, great care must be given to the choice of mixture, control of melting practice, etc., in order to give a metal composition which gives a perfectly white structure throughout all sections, and at the same time allows ready response to subsequent malleablising treatment.

The photomicrographs A and B show structures of blackheart malleable iron taken from the same casting produced under strict metallurgical supervision. It should be noted that in spite of the considerable difference in section both structures are similar, except for a little larger ferrite grain size in B, and what is most important is that the graphite in both consists of the "temper carbon" variety only. There is no free carbon in the material before annealing, and that seen in the photomicrographs is actually precipitated during annealing treatment, and, apart from a very small loss on the surface due to decarburisation during the process, is almost equal in amount to that present as combined carbon in the hard state. This temper carbon of nodular or rosette formation breaks up the continuity of the ferrite matrix to a very much less extent than primary graphite of the plate type, and that of cellular formation which is often found in badly mottled material before annealing.

The successful execution of this work is just another proof of what the British malleable industry can do, and should do much to open up a new field for the extended use of blackheart malleable cast iron both at home and abroad.

The Controller of Iron and Steel has agreed to the release of Mr. Felix Levy, a director of George Cohen, Sons and Co. Ltd.

Mr. Levy was seconded in September, 1939, to the Ministry of Supply, where he has been Assistant Director of Scrap Supply. He will now devote his time to the administration of George Cohen, Sons and Co. Ltd. and their Associate Companies.

Keltic Metal Work and Manuscript Illumination*

By Douglas Rennie Hudson, B.Sc., Ph.D.

Lecturer in Metallurgy, Heriot-Watt College, Edinburgh.

"Hibernian Art at its best was, even in matters profane, essentially a monastic phenomenon."
A. Mahr, 1941.

"That the Irish system of ornamentation does actually find an analogy in Eastern countries is proved by the illustrations published by C. Knight in a small work on Egypt. We find there the serpentine bands of the Irish ornaments appearing already in the oldest Egyptian and Ethiopian manuscripts and with a similarity of colour and combination truly astonishing."
F. Keller.

ABSTRACT.

From critical assessment it appears that the Keltic Style developed from Continental La Tène; the whorls, trumpets and scrolls may be correlated with Aegean patterns. Irish penannular brooches may be traced back to Halstatt and eventually to spectacle *fibulae* from the Balkans. Following St. Patrick's evangel, sublimation led to a vigorous mission throughout Europe, from Iceland to Italy. Foundation of famous monastic workshops led to a magnificent *floruit* about the 9th century, but the christianization of Bavaria and Switzerland by the Keltic Mission is better known. Red enamel, probably introduced about A.D. 200 from Wales, where yellow and blue also flourished, became characteristic of Irish monastic work. Designs in manuscript illumination, which led the world, are shown to be derived from the intricate patterns of metal interlacing, and the author suggests that decoration in red dots (to the exclusion of other colours) is a copy of the orange-red spots in Irish *cloisonné*. Early *Scotic* metal tradition, which stood so high while Europe sank back into barbarity during the dark ages (400–1000), profoundly influenced Occidental craftsmanship for a millennium, not only in metal work but in the derived art of manuscript ornamentation, right down to the invention of printing from moveable types. In the zoomorphic designs of hideous distorted lizards and birds the Keltic is modified by strong Teutonic influence.

The Book of Durrow

This manuscript, in possession of Trinity College, Dublin, consists of 248 pages in half-uncial script. Its *colophon* reads :—

Rogo beatudinem tuam sce praesbitere patricii ut quicunque hunc libellum manu te nuerit meminerit columbae scriptoris qui hoc scripsi himet evangelium per XII dierum spatium gtia dni nri s.s.

Under this is written in another hand :—

Ora pro me fra ter mi dns tecum sit.

I ask thy beatitude, o holy priest Patrick, that whosoever may hold this volume in his hand may remember Columba the writer who have written this gospel in the space of twelve days. By the grace of our Lord.

Pray for me my brother, the Lord be with thee.

Decoration.—Patterns are far more primitive and the analogy with metal work more striking than in any other Keltic manuscript. Compare Fig. 6 with the patterns on the older cover of the Lindau Gospels (Fig. 9) and with the shrine of Dimma's Book (Fig. 8). Yellow, red and green colours are used, but not silver and gold. The pages have suffered from rubbing, and in some cases are very discoloured, probably from age rather than damp. No trace remains of the silver *cumhdach* in which it was cased by King Flann (879–916) recorded in an entry dated 19 June, 1677. Trumpet and interlacing designs are well to the fore; by comparison of the simple and pleasant primitive ornament with other examples of Scotic work, it seems unlikely that this book should be dated later than A.D. 650, and in the author's view it might easily be a century older. The canons are set out very simply.

* Continued from page 290, April, 1945.

3. CORRELATION OF RED DOT DECORATION IN MANUSCRIPT ILLUMINATION AND CLOISONNÉ ENAMELLING

Embellishment of Keltic illuminations with red dots, often of square shape and inclined at 45° as diamonds, is quite characteristic. Red seems to be the only colour used in this way, just as isolated spots of orange-red in *cloisonné* are considered typically Irish (at least after the 2nd century A.D. when coloured enamels died out in Wales) in whatever part of Europe, or whatever monastic foundation, they may appear. The author feels on firm ground in correlating the two applications of *red*, to the almost complete exclusion of other colours. This is further evidence for derivation of illumination patterns from the tradition of metal craftsmanship.

4. THE ARDAGH CHALICE

This *calix ministralis* was part of a hoard including two chalices and four delightful brooches discovered in an earthen fort Reerasta Rath near Ardagh, and has been studied in detail. The two-handled type was extensively used by minor clergy and laymen, according to the older *Ordines Romani*, before A.D. 900. A plain bronze chalice, though smaller is very similar in shape. (See Fig. 7).

Workmanship is good and the craftsmen used a variety of metals with great success. Estimates of its age have varied from the 7th–11th century A.D., showing as great a latitude as for the Gospels of Kells. In view of the different styles and materials it is quite possible that the chalice is a composite work or that an earlier vessel has been reworked by different craftsmen. The silver cup is delicately chased with the names of the apostles, and surmounted by a brass rim 9½ in. in diameter. It is attached very ingeniously to the gilt

bronze stem by a tang and iron bolt, the overall height is about 7 in. This in turn is fastened to a silver foot, with ornamental plaques backed by mica and alternately of gold and gilt bronze. The earliest part of the decoration is also the finest artistically—fine scroll and trumpet designs, typically Keltic, around the crystal in the underside of the chalice, and above and below the cylindrical stem. Other parts, in which cairngorms and granulation are used, are obviously later in style ; in the handles gold filigree is enriched with amber and blue (glass ?), Keltic artists never hesitated to use to advantage the violent contrasts of bright colour against bright metal. The interlacing animal and scroll patterns in the cylindrical band surrounding the bowl is strongly reminiscent of manuscript illumination, the *repoussé* work is in gold.

Fig. 11.—Aegean pottery vase, with stylized glyptic and architectural design, possibly in imitation of bronze-work. "Great Palace Style," Late Minoan II, c. 15th cent. B.C.

5. THE SHRINE OF ST. DIMMA'S GOSPELS

This typical " book shrine " of silvered bronze enriched with quartz gems, found in Devil's Bit Mountain, is in possession of Trinity College, Dublin. While it is clearly composite in workmanship, the inscription shows it to have been made for Tatheus O'Kearbaill, about 1150 by stylistic analysis. The crucifix and human figures on the back (Fig. 8) are clearly later, possibly 13th century, but the interlaced and cruciform quandrants and the animal backgrounds on the front, are earlier. Doubtless it was an early *cumhdach* reworked into a shrine.

6. EVANGELIA QUATUOR OF LINDAU

The metal covers of the Lindau Evangelary are first-rate examples of jewelled primitive metal work. A critical appreciation has been published by NESBITT.—

" We have a most unusual, probably even an unique, example of the juxtaposition of several artistic processes. Enamelling, both *cloisonné* and *champlevé*, garnet work, or, as it has been called, *cloisonné jewellery*, and metal sculpture of Irish character, are all well known, but this is the only instance, so far as my knowledge extends, in which all four processes are employed in conjunction.

The enamels are chiefly executed by the process known as *cloisonné* in which fillets of gold or other metal are soldered to the ground and form cells, in which the enamels are placed before the work is exposed to the action of the furnace. In some instances, however, as at the extremities of the cross, the enamel has been placed in hollows excavated in a plate of metal. In many places spots of orange enamel have been placed in cavities cut in the blue, no line of metal intervening and separating the colours, the orange enamel being no doubt the more fusible. This method of treating enamel is common to the (probably) Gaulish enamels of the antique period, and to Irish enamels of the 9th or 10th

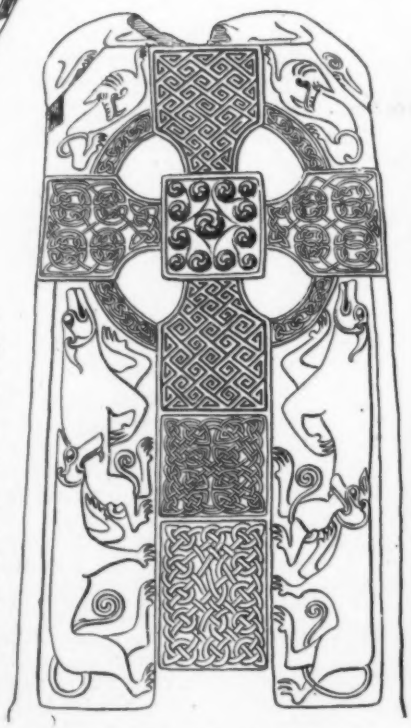


Fig. 12.—Slab with engraved cross of St. Madoco, Perthshire.

Fig. 13.—Slab with engraved cross at Aberlemno, Forfarshire. (After Allen.)

Compare the fantastic animals with the Tara Brooch (Fig. 3), the interlacing ornament with the Ardagh Chalice (Fig. 7) and the manuscript patterns of Durrow (Fig. 6) and Lindisfarne (Figs. 4 and 5).

century, as, e.g., the fine chalice now in the museum of the Royal Irish Academy.

. . . In this instance it seems probable that the enamels were fabricated in some one of the South German monasteries, where Irish monks were among the inmates; for, besides that the design of the monstrous beasts and birds has much of the character of Irish art, it will be remarked that the enamel of a peculiar orange red is frequently introduced. Enamel of this colour is not confined to objects of Irish manufacture, for it may be found upon brooches and other small articles found in France and Italy, and preserved in various museums, which may be with reason supposed to have been made in Gaul; but it was frequently employed by Irish artificers; and a similar colour is somewhat conspicuous in manuscripts of the Irish school, such as the Lindisfarne Gospels in the British Museum.

Blue opaque enamel, on the other hand, is, I think, rarely if ever found on objects of Irish origin; and no Irish enamel is known to me in which the human figure is, as here, represented.

The system of ornamentation by means of thin slices of garnet set in partitions of gold, which is found on this side of the book-cover, is familar to us in England as occurring on the brooches found in the graves of the Anglo-Saxon inhabitants of Kent; it occurs also on many objects of personal decoration and weapons found in Germany, France, and Italy . . .

These examples would all appear to range in date from the 5th–7th century, and we do not seem to meet with the employment of this method of decoration on objects dating from the 9th or 10th centuries; it would appear to have gone out of fashion after about A.D. 800, and the example before us would seem to be perhaps the latest in date which has been hitherto noticed.

. . . the sculpture in metal, which is the method of decoration of large portions of this cover, is characteristically Irish in design . . .

[At Kremsmünster monastery] a chalice has been preserved which bears the name of Tassilo, and this also is ornamented with patterns of interlacing animals, some parts of which are almost identical with those on the book cover; the forms of the letters on the two objects are closely similar and the work is executed in the same manner by cutting out the metal in cavities terminating in angles." (See Fig. 14.)

Dating.—The date of this can be fixed very accurately by the fact that Tassilo was deposed in A.D. 788. It is of copper and has been attributed to the Keltic Missionary Church which introduced Christianity to Switzerland and Bavaria, but Anglo-Saxon provenance is not impossible. NESBITT believed the older cover to be contemporaneous with this chalice and possibly even a gift from the same individual to Kremsmünster. In 1803 when the Lindau nunnery was dispersed, and the *textus* came into private hands, a tradition existed that it dated from its foundation in A.D. 834, which would check the above estimate very well.

The Lindau Manuscript

The manuscript, some 220 leaves of vellum each $12\frac{5}{8} \times 10$ in., consists of St. Jerome's text of the four gospels, with prefaces, etc., in a bold German miniscule hand with contemporary corrections, assigned unhesitatingly to the 10th century A.D., and written by several scribes. Initial letters are generally capitals with rustics and uncials, in gold on a purple background. Green, yellow, blue, and grey are used in illumination and purple fly-leaves are used for the Eusebian canons. The manuscript is beautiful but not outstanding as are the jewelled casings.

Design and Functionalism

Evangelia Quatuor now in possession of Mr. J. P. Morgan, of New York, is a *textus* typical of mediaeval church equipment. One was usually deposited at each end of the high altar and until the 11th century it was customary to carry it round the congregation to receive a solemn kiss (*pax*) of peace. According to Gregory of Tours, Childebert in A.D. 531 brought from Barcelona 20 jewelled gold *evangeliorum capsas* cases of gospels (*capsa* = box, perhaps *casing* in the bookbinder's sense). Workmanship vied with the costly metals and fine gems, and the great beauty of these jewels is immediately apparent to the layman, without technical skill or experience (Figs. 9 and 10). The functionalist would be the first to admit this, while reserving the right to point out that an ornament admirable for a bishop's crook or a shrine is downright absurd for a book cover subject to daily rubbing and abrasion. Such a contention would be abundantly justified by the large number of repairs which have been carried out—albeit very skilfully. The greater part, however, is still the original work.

Fig. 14.—The Tassilo Chalice in possession of Kremsmuenster Abbey since its manufacture c. A.D. 780. The three parts are of hammered copper with concealed joinings. Christ and the Evangelists are shown in "niello" on the five elliptical silver medallions, with inscription TASSILO DVX FORTIS + LIVTPIRG VIRGA REGALIS +. "Scotic" influence is apparent but general treatment is Teutonic, quite lacking Irish delicacy. Reproduction one-third actual size.

No doubt it will shock many antiquaries and lovers of fine art to express regret that the materials—gold and gems—used in these jewels, are of such intrinsic value. Had their worth as scrap, apart from the craftsman's settings, been less, there is no doubt that many precious covers, of incalculable value to-day, would have escaped the melting pot, and probably many more fine manuscripts would remain to us. One may recall the Book of Kells, which was stolen, the manuscript being later recovered in a damaged state, torn from its casing by the thief; the covers were never found. The incredibly stupid British law of treasure trove by which valuable objects become forfeit to the Crown after all the wasteful anachronisms and quaint usages of the Crowner's Quest, has caused the loss or dissipation of treasures of craftsmanship priceless from an archaeological and scientific viewpoint. Even the present compromise, whereby the lucky finder is compensated by the scrap value of his artefact, is thoroughly unsatisfactory. To obviate such distribution as occurred in the case of Northumbrian silver artefacts recovered from the Tyne in the middle of the 18th century, of which we know very little, some control is obviously necessary. Surely this could be operated by compulsory auction, followed by the right of pre-emption by a national collection. However, while the Treasury stranglehold continues, one can hardly expect fortunate finders to observe a law which in its implication comes very near to judicial theft, and which in most cases is quite beyond enforcement. Meanwhile, our archaeological *corpus* continues to be dissipated.

The Older Repaired Keltic Cover

The enamelled cross is probably silver gilt or low grade gold alloy, the convoluted pattern within the rectangles apparently a tin-rich pale bronze. These statements must be taken with reserve, since, so far as can be traced, the many dissertations on the jewel have all been executed (and most efficiently) from stylistic and artistic viewpoints, and no competent metallurgical examination has ever been carried out. Its *leit Motiv* is an interlacing of lizards or wolves. In the centres, three of the original smoky quartz rectangles surrounded by garnets have been lost and replaced by pastes set in gilt. At the corners chased figures of the four evangelists, winged, have been substituted for the original ornaments. These, depicted with the appropriate symbols, are later work, probably about 1600.

At both vertical edges strips of gilt metal dating perhaps from the 9th or 8th century, have been added. On the right side the fine border of *blue* enamel and garnet work is wanting having been replaced by a later border of *black* enamel set with garnets at the bottom, and by two similar riveted plates at the left-hand corners. The jacinth (?) at the centre is a substitute for the original diamond ornament. It is surrounded by IHS, XPS, NOS in blue and orange enamel, and DNS engraved on a triangular gold plate—**JESUS CHRISTUS DOMINUS NOSTER.**

The four figures of blue enamel on bronze, incorporated in the arms of the cross at the centre, are very rudely executed. The small circles are set with mother of pearl spheres replaced in some cases by turquoise and fractured carnelian (?) At present the cover measures $13\frac{1}{4} \times 10\frac{3}{4}$ in., the various components, original and replacements, being pinned on a half inch board, its edge covered with strips of gilt metal with 16th century lettering.

The Jewelled Ninth Century Cover

NESBITT believed this Lindau casing to be contemporaneous with the *ciborium* in the Reichs Kapelle, Munich, made for Emperor Arnulf between 896 and 899. "It seems, in fact, very probable that both came from the same workshop." LABARTE drew a most persuasive correlation between this later, richly jewelled, side, and the original cover of the *Codex Aureus*, broken up by Ranould, abbot of St. Emmeran Convent about 875, some gems being employed in ornamentation of chalices, and the cover re-made in a more tasteful manner, perhaps as we have it to-day. The chronicler Arnuld described four large emeralds arranged as a cross, each surrounded by four pearls set in minature chalices "*gemmarum . . . quarum quaedam adeo quantitate preminent, ut quatuor ex his calices operiant sedecim, in figuram sanctae crucis, per singulos quaternis ordine medio dispertis.*" Within this were 32 lesser stones—*triginta duos, singulatim gemmis minoribus opertos.* (Fig. 10).

Fig. 15.—Shrine of the Bell of St. Patrick's Hill (back). Gold. Note the cross and swastika pattern, and the interlacing metal work at the side; the front is ornamented even more richly, and set with cairngorms, possibly later additions. Compare with Fig. 8. c. A.D. 1100. "Clog an Edachta." National Museum of Ireland. Reproduction one-third actual size.

This cover, too, consists of a gold cross, formed of raised open work in the shape of claws, and granulated. One can well imagine how ideal this design was both for

abrasion and for entanglement in loose fibres or fringes of an altar cloth! Christ is represented in primitive *repoussé*, with blood gouts issuing from stigmata on hands, feet, and right armpit. The metal work is jewelled with incredible richness, most of the stones seem to be the originals and they and the pattern correspond well to the fundamentals of Arnuld's account. Sapphires and emeralds are rough polished rather than "cut"; moonstones, carbuncles and onyxes are *cabochon* "cut." A few faceted gems are probably replacements for lost originals; the larger pearls are believed to be Scots. The edge of the mounting board is covered by gold strips set with carbuncle, sapphire, amethyst, chrysophrase and jacinth. In Ireland, early *capsas* were reworked in large numbers in the period of Later Animal Style (1000–1250), and survive to-day as book shrines—e.g., the Stowe Missal. Compare also Figs. 8 and 9.

Probably this casing is the finest example of Carlovignian period that remains, though Charlemagne and his successors are famous for their patronage of the arts, and many fine specimens of the work of his Irish artificers have come down to us. The manuscript is, quite obviously to the experts, younger than the jewelled *capsa;* beautiful in itself, it is of no special historical value.

7. CONCLUSION

It is not too much to say that *Scotic* metal working tradition, both directly and through the cognate art of manuscript illumination, exercised a profound influence on two crafts throughout the western world for nearly a millennium. Keltic influence on penmanship and lettering, in Britain and more especially on the Continent, can be traced right down to the invention of printing by moveable types.

The brilliant sparkle of Irish intellectualism is well known and universally appreciated. Yet who, looking back on the troubled and unhappy little country for the past five centuries, would credit it with such a glorious background in the arts—more especially in such highly specialized and strongly individual crafts as metal craftwork and illumination of manuscripts? Yet for five hundred years this small and inhospitable island was the flourishing centre from which not only a vigorous missionary Christianity but a magnificent and unrivalled tradition in the arts spread far and wide into a world rapidly sinking back to barbarism.

One fascinating problem deserves the archaeologist's attention. From metal working we may quite reasonably derive the *Motiv* for manuscript illumination. Are we entitled to derive from it almost identical patterns on Keltic crosses in stone? If not, shall we revert to a common archetype for all three crafts; and if so, what and where? And the newer stone crosses which reproduce interlacing decorations and zoomorphic patterns of the manuscripts so exactly (Fig. 12 and 13) down to the very panels, should we regard these as direct copies of the painted vellum illuminstions?

The great antiquary ROMILLY ALLEN grasped this nettle firmly. Regarding vestigial stone bosses on sculptured stone crosses as analogous with bolt or rivet heads (e.g. on the Processional Cross of Cong) he was bold enough to derive stone craftsmanship from pre-existing metal prototypes.

"Hayden-Nilos" Hose Joint

THE Hayden-Nilos hose joint was introduced to provide a simple and most effective method of joining lengths of hose carrying air or liquids under pressure. Obviously the first requirement of such a joint is that it shall be leakproof, and on this point some remarkable test figures are available. The Hayden-Nilos hose joint comprises specially designed hose-to-hose connectors and neat and extremely strong clips. A compact tool (weight 2 lb.) draws the clip dead tight, locks it and cuts off the surplus strip.

The advantages of this system are first that joints can be made in already connected hose; there does not have to be a free end for the clip to be slipped over, nor is there the risk of distortion always present where preformed clips have to be opened and sprung over the connected hose. Three standard lengths of strip suffice for all sizes of hose from ½ in. inside diameter upwards. The hose-to-hose connectors are supplied in diameters to suit all sizes of bores and are so designed that the clip holds the hose firmly all round and tight against the connector. The clip is always the exact size to fit the hose, regardless of variations of external diameter of hose of the same nominal bore.

The manufacturers of this hose joint were recently asked by Brown Bayley's Steel Works, Ltd., whether a hydraulic pressure of 1,300 lb./per sq. in. could be handled as this was the pressure they required for their furnace charger. A sample length of armoured hose was supplied and this was then fitted with a ¾ in. Hayden-Nilos coupling at one end—the other end being suitably plugged. Hayden-Nilos clips were applied, three at each end, and the hose was submitted for test to the Sheffield Testing Works, Ltd.

The various components of the Hayden-Nilos Hose Joint and the simple method of application.

Hydraulic pressure was applied and the pressure brought up to 2,000 lb./per sq. in. with no leakage at the joints. Then further pressure was applied until 9,700 lb./per sq. in. was reached, at which point the hose burst, leaving clips and couplings intact and with not the slightest sign of leakage.

Such pressures as these are many times in excess of the working pressures required by the shipbuilding, coal-mining and other industries using air or water pressures in flexible pipe lines.

Aluminium Development Association

THE president (Hon. Geoffrey Cunliffe) and the Council of the newly formed Aluminium Development Association gave an inaugural luncheon at Claridge's on May 10, 1945.

Among a distinguished gathering was the Right Hon. Sir Stafford Cripps (Minister of Aircraft Production) and the Right Hon. Hugh Dalton (President of the Board of Trade). In proposing the health of the guests, the Hon. Geoffrey Cunliffe said: "It is a great pleasure and privilege to have you here to-day to celebrate the opening of the Aluminium Development Association. The purpose for which we have formed this Association is, I think, fairly clear, but we will in the first place go back to the early days of the war when the industry was expanding and we were faced at that time with the voracious demands of the Air Ministry."

He went on to say that the new Association intended to carry out propaganda, but that this would be directed not simply to the sale of aluminium. It was a common fault to say you have plenty of something, and therefore must use it for everything. Aluminium should be used only where it ought to be used. There were three main platforms for the new Association. One was to develop by practical means, and not merely by old-fashioned sales talk. Secondly, the Association would encourage research, which after all is the basis of all industrial development and achievement. Thirdly, propaganda and advertising would be used in what it is hoped would be an intelligent manner.

"I think," he ended, "that in a relatively few years of difficulty we will be able to absorb the skilled labour in fabricating and handling aluminium, and in a very short time we will all be shouting for more."

Sir Stafford Cripps in reply, struck a significant note when he said: "I need not stress the importance to the aircraft industry and to my Department during the war of aluminium and the light metals industry. All forms of transport naturally demand the lightest practicable material consistent with the strength required, but this is pre-eminently so in the aircraft industry when 50–60% of the overall weight of an aircraft is made up of light alloy materials. The development in the strength of these alloys has been very remarkable, but of course there is still a huge field for fresh advances. Our superiority in the air in the future will depend to no small extent upon the ingenuity and patience with which we can by our research and development keep ahead in this fascinating and important field of metallurgy.

"I should like to take this opportunity of thanking the whole personnel of the industry for a most remarkable contribution to our Victory. Managements, scientists, technicians and staffs and workers have all made their contribution to a team work that has kept the aircraft, the aero engine and other manufacturers supplied, and so maintained the supply of aircraft for fighting men of the R.A.F. and F.A.A. . . . Perhaps more than in almost any other industry success will depend upon the vigour and imagination with which you pursue your development policy, and that is why I welcome so much the setting up of this Association. I hope that nothing will stand in the way of its effectiveness, and of the work it will do for the country."

Mr. Hugh Dalton also addressed the assembly, and particularly emphasised that aluminium represented "a young, expanding, and hopeful industry." He endorsed all that Sir Stafford Cripps had said about aluminium and added: "With reference to the continued employment of workers who have been trained in the handling of this metal in the various stages of production, the Government attach very great importance to this employment problem. You have built some of the most modern plants just in those areas where an increase of employment is most necessary. For that reason the Government look upon you with a most hopeful eye and wish you to continue to work those factories in areas where before the war there was permanent unemployment."

Mr. H. G. Herrington (chairman of the Management Committee of the Aluminium Development Association) having thanked those present for their attendance at the luncheon, said: "We have an enormous output to sell, but we relish the fight that it will entail. Fortunately, we are a young, a virile industry, not yet hampered and shackled by the results of our own misdeeds. We feel, therefore, that we can go forward with sober confidence. Conscious of what we have achieved, aware of our limitations, we shall seek to establish ourselves as a vigorous and enlightened Association supported by a sound and healthy industry."

Imperial College Centenary Celebrations, 1945

Presuming that the war in Europe will by then have terminated, the Imperial College is planning to celebrate next autumn the centenary of the Royal College of Chemistry, from which, through two of its three constituent colleges, it can trace descent. The third week in October is contemplated, and it is hoped that H.M. the King, as Visitor of the College, may find it possible to be present. In connection with this centenary the College has recently launched an Appeal for funds.

The Imperial College of Science and Technology, constituted by a Royal Charter dated July 8, 1907, is a federation of three constituent Colleges—the Royal College of Science, the Royal School of Mines, and the City and Guilds College (formerly the Central Technical College of the City and Guilds of London Institute); and these in turn were related with earlier institutions from which, accordingly, the Imperial College can trace descent. The earliest of all, the Royal College of Chemistry, is that of which the centenary falls in this year. Its first president was H.R.H. Prince Albert (later the Prince Consort), who had also opened (1851) the Museum of Practical Geology in Jermyn Street, with which de la Beche associated his "Government School of Mines and of Science applied to the Arts." From this source, later, both the Royal School of Mines and the Royal College of Science derived, and the name of the Prince Consort is thus associated with two of the constituent Colleges of to-day.

The Imperial College is a School of the University of London. Subjects at present available for study or as fields of research include Biochemistry, Biology (Botany, Entomology, and Zoology); Chemistry (Agricultural, Inorganic, Organic, Physical); Geology; Mathematics; Physics (including Astrophysics and Technical Optics); Metallurgy; Mining (including Mining Geology and Oil Technology); Engineering (Chemical, Civil, Electrical, Mechanical); Aeronautics. In them all the instruction has by tradition a strong bias towards the practical and industrial applications of science.

Probable Post-War Trends in Heat-Treatment

By A. Glynne Lobley, M.Sc., A.M.I.E.E.
General Manager, Birlec, Ltd.

With the accelerated advance of the application of science to industry in the manufacture of high-grade and specialised products considerable progress has been achieved in heat-treatment plant. Many types of furnaces are of such a high order that they may be regarded as precision tools and can be operated successfully in the line of production. In dealing with post-war trends, the author gives special attention to this aspect of heat-treatment and cites a few types of continuous furnaces. Increase in the use or gas carburising and heat-treatment by induction heating comes in for special reference.

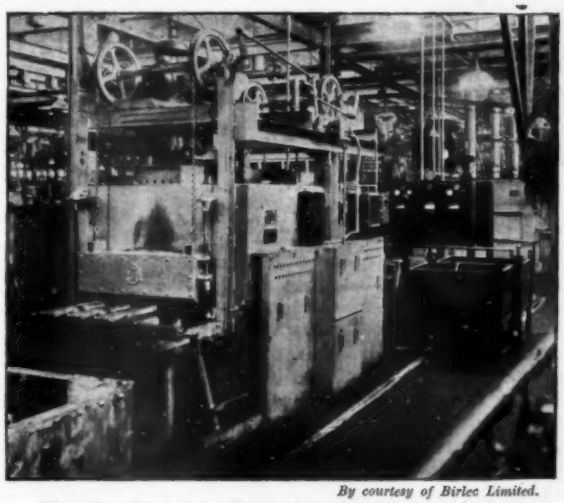
THERE is no doubt that to-day it is very generally realised in this country that industry must, in its replanning, use the most up-to-date methods available. This has been brought about by a number of factors.

In the first place there is the necessity of exporting manufactured goods, which has become so much more urgent owing to the loss of overseas investments and, consequently, of the "invisible" exports which were previously relied on to make up for adverse trade balance. Together with that is the fact that many countries to which manufactured goods were exported have now, under the pressure of war requirements, become industrialised. One possibility, however, is that highly specialised and high quality goods will still have to be imported by countries which may no longer require the more ordinary type of manufactured goods.

On the other hand, in such high-grade and specialised products Great Britain will have to compete with the United States and other countries which are not only well able to produce such goods but will have surplus production capacity driving them to export everything possible. Not only will this competition be felt in the overseas market, but in this country. Indeed, before the war many specialised engineering products were imported into this country, products which, with enterprise and encouragement, could equally well have been made here. This was partly due to the fact that many new machines were first made in America under the stimulus of its larger and more receptive market, and our industries bought these machines rather than risk buying the newer and less tried developments of British manufacturers. This country can no longer afford to do this, everything that can possibly be produced here must be, both for our use and to export in exchange for the imports of food and raw materials essential to our industries.

It is also clear that there has been an accelerated advance in scientific achievement and in the application of science to industry during the war, and that only by making use of such methods under peace conditions can industry hope to compete in quality or in cost.

Whilst much has been done in the applied sciences of radio, plastics, chemical industry, etc., which the public has been told will revolutionise all kinds of things in general use, there has been continuous and, in many cases, remarkable progress in metallurgy. In practically every case the special and improved properties of modern alloys, both ferrous and non-ferrous, are achieved through the aid of heat-treatment, heat-treatment, that is, under



By courtesy of Birlec Limited.

Fig. 1.—55 k.w. pusher furnace for camshafts.

rigid, accurate, and reproducible conditions which were not obtainable in the older types of furnaces.

It has been stated above that specialised engineering products could be made in this country and the need to go abroad for them obviated if the natural inventive genius which exists here were encouraged and given proper scope. For many years before the war, in spite of all that had been done, there was not sufficient high-grade heat-treatment plant in the country to meet its real needs. The consequence was that when the war came, with its urgent requirements of proper heat-treatment in all phases of munition manufacture there was probably a greater shortage of such equipment than there was of almost anything, even of, for example, machine tools. An immediate and heavy demand was made on the high-grade furnace industry (electric and other types), a demand that persisted practically throughout the war, and it is a matter of pride to the industry that the demand was met without any recourse to foreign importations (with possibly some insignificant exceptions). If this could be done in the furnace industry under the stress of war-time demand, it can surely be done under the pressure of our post-war conditions. The furnace or heat-treatment equipment industry is able and anxious to assist engineering and other industries to play this part.

In what directions can advances in heat-treatment equipment be mainly expected?

By courtesy of Birlec Limited.

Fig. 2.—Two 80 k.w. continuous conveyer bright annealing furnaces.

In the first place many of the types developed before the war will persist, but there will naturally be improvements in detail which will increase efficiency, and then will certainly be cleaned up, or so-called "streamlined" in appearance. This latter has come to be generally demanded, although it increases cost and sometimes detracts from convenience in use, particularly in the matter of accessibility for oiling, repairs, etc. Under this heading there are the toolroom and other batch-type furnaces, which, as previously, will use special atmospheres where necessary to prevent decarburisation, oxidation, etc.

Heat-Treatment as a Flow Line Process

It has long been the dream of the engineer and factory planner to have the various heat-treatment processes in the line of production.

When furnaces were crude and smoky and accompanied by equally messy quenching and similar equipment, it was not possible to do other than segregate such work into a separate shop. This no doubt helped to produce the atmosphere, often still found, in which the heat-treatment department is a Cinderella provided with inadequate equipment and the least intelligent of operators.

Gradually, however, and mainly with the advent of the electric furnace, it has been possible to put the heat-treatment equipment in the line of production. The electric furnace particularly lends itself to being placed in any desired position owing to its inherent cleanliness, with absence of flues, stacks, etc. Flues or stacks for removing the waste gases from fuel-fired furnaces are often an obstacle to putting such furnaces in the production line, as they interfere with cranes and overhead conveyers, etc., whilst the heat losses from the furnace and flues often make working conditions in the vicinity bad.

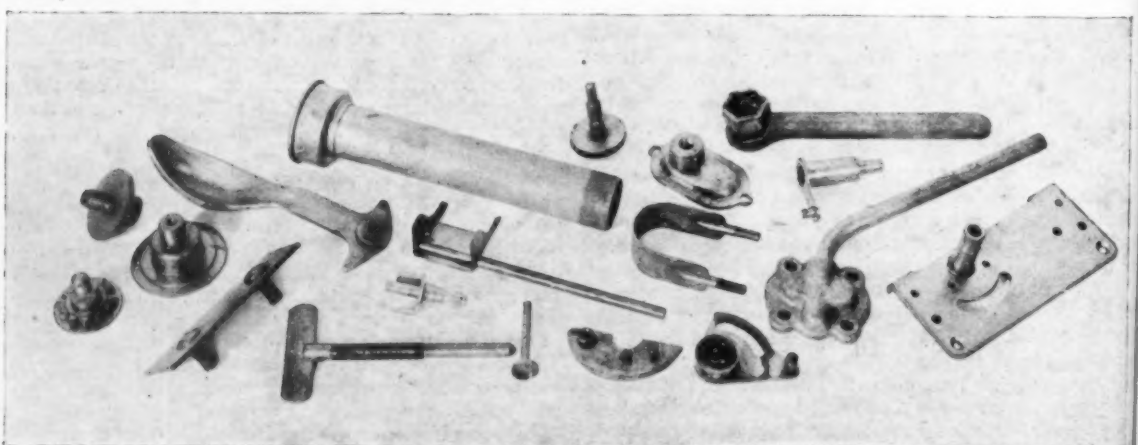
In the replanning of factories every effort will doubtless be made to put furnace equipment in the line of flow where doing so can add to efficiency of production. Improvements in furnace equipment and the advent of new processes will facilitate this arrangement and it may, therefore, be opportune to consider some of the developments which have taken place in the light of the effect they may have in this direction. In this connection some instances of what has been done may also be of interest.

Continuous Furnaces

The continuous type of furnace is obviously most suited for being placed in the line of flow of production. In a number of factories, particularly in the automobile industry, this method had been adopted to a considerable extent some years before the war for many of the components being manufactured.

Fig. 1 shows a pusher-type electric furnace installed many years ago in a motor-car factory, for hardening

Fig. 3.—Some examples of electric furnace brazing.



By courtesy of Birlec Limited.

camshafts. This furnace was in the line of flow and the camshafts were pushed through on carrier shoes and automatically removed quickly from the discharge end and then placed in a spinning quenching machine.

Bright annealing, when done in a continuous furnace, may often with advantage be carried out in the main shop. Fig. 2 illustrates two bright annealing furnaces where the components are being placed on slowly moving heat-resisting belts. By this means the charge is carried through the furnace and then through a water-jacketted chamber in which it is cooled below oxidising temperature. The furnace and cooling chamber are filled with a suitable atmosphere to prevent oxidation so that the annealed product is bright and clean, and no pickling is required. Instead of a belt conveyer the charge may be carried on trays which are pushed through the furnace, or on rollers, externally driven. This last method, which is particularly suitable for the bright annealing of strip, rod, and tubes, has the great advantage that no heat is wasted in heating belts or heavy trays. For some components trays may have to be used, carried on the rollers, but they can be much lighter than trays which have to withstand being pushed. The roller hearth type of furnace has also the advantage of lower maintenance costs, but the capital expenditure involved is higher than for the belt type.

Any of these furnaces can be heated by gas instead of by electricity, radiant tubes taking the place of the electric elements. There is now a patented type of radiant tube which is recuperative, so considerably increasing the thermal efficiency.

The question of whether to use gas or electric heating is an economic one, chiefly to be decided by the relative costs of supply. In the case of the above types the capital and maintenance costs of the gas-heated furnace are somewhat higher than those of the electric. Furnaces have also been built where gas heating is used for the first part of the furnace and to provide the special atmosphere, and electric heating for the later zones, where the material reaches its final temperature.

The atmosphere used for all these furnaces is most commonly produced by the incomplete combustion of coal gas followed by cleaning and removal of excess moisture. The degree of combustion is controlled to suit the metal being treated. Other gases are also used in bright annealing, such as burnt ammonia, which is nitrogen with a hydrogen content varying between 2% and 20%; charcoal gas, which is mainly nitrogen and carbon monoxide, and modified burnt coal gas.

In most continuous furnaces the material being annealed is either mild steel or a non-ferrous metal, so that there is no question of decarburisation to consider. Where a high-carbon steel has to be treated and it is important to prevent all decarburisation special gases must be used; burnt coal gas not being suitable (without special treatment) owing to the high content of the decarburising gases, carbon dioxide, hydrogen and water vapour.

By courtesy of Birlec Limited.

Fig. 4.—A small continuous copper brazing furnace.

In general, practically all metals can now be bright annealed, provided the equipment is properly designed for the purpose and the correct gas used. To-day it is even possible (by a patented process) to bright anneal stainless steel—metal difficult to so treat owing to the great affinity of the chromium for oxygen or moisture, even an extremely small trace of either of these being fatal.

Electric Furnace Brazing

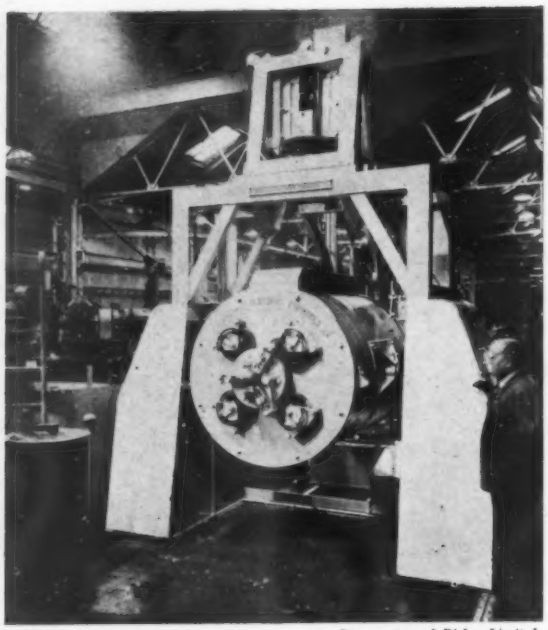
Furnace brazing with copper or lower melting point brazing alloys will undoubtedly play a major part in post-war developments. This process is nearly always carried out in a continuous furnace similar to those for bright annealing. The atmosphere prevents oxidation and cleans the component of oxide so that no flux is required, where pure copper is the brazing material. This method has been described in detail on many occasions during the last few years, and not being, strictly, a heat-treatment process, does not call for description here. It is, however, so important that emphasis must be placed on it. Provided the engineer will so design his components that full advantage can be taken of this process, anyone with imagination should be able to visualise what a great effect the process can have on the quality, variety, and cost of many parts required in modern appliances and machines.

Fig. 3 shows a few examples of the almost infinite variety of parts which may be joined by copper brazing, and it might here be emphasised that provided the clearances are small the joint will be stronger than the main body of mild steel.

Fig. 4 is an illustration of such a furnace showing parts being loaded on to the furnace wire mesh belt. This again is a process which may readily be carried out in the line of production.

Gas Carburising

Another process which will come into greatly increased use is that of gas carburising. With this process, as distinct from carburising in boxes, greater uniformity in a much reduced time is achieved. The absence of boxes



By courtesy of Birlec Limited.

Fig. 5.—A special rotary retort furnace for carburising.

and compound brings about a great saving in heat requirements which considerably cheapens the direct costs of carburising where thin or medium cases only are required. A continuous supply of a special carburising gas is required and this fact neutralises the direct savings where abnormally thick cases are required. In all instances, however, there is the appreciable saving in time, trouble, and space in dealing with the boxes and compound, and the great advantage that the dirt and dust inevitably associated with the use of compound is entirely eliminated. This last fact now enables carburising to be comfortably added to the processes which can be carried out in the line of production.

In most cases gas carburising is carried out in batch type furnaces of the fixed or rotary retort types, but it can be done in continuous furnaces, where there is a sufficient quantity of a component to be treated.

The rotary type of furnace can either be used with gas or with a small proportion of compound. Fig. 5 shows a rotary carburising furnace having automatic features not normally provided but specially demanded in this instance, and which may, therefore, be of interest. The charge consists of very small parts which it is essential should all be uniformly carburised. The normal rotating position of the drum is naturally horizontal, as shown in the illustration; when the process is complete the furnace is brought into a vertical position and a special appliance (shown at the top of the illustration) removes the bung. The furnace then tilts forward and ejects the charge into a quench tank (not shown in the illustration). After emptying, the furnace again goes to the vertical position and continues slightly beyond it, when a new charge is automatically poured into the retort. On returning to the vertical position the bung is re-inserted and the furnace then returns to normal position, when the carburising cycle re-commences.

Gas Malleabilising

A new process has been invented which, because of its importance and interesting nature, deserves brief mention here, although it will usually be operated with batch-type furnaces in a special shop. It could, however, be used in the main shop if there were reasons for so placing it. This is a new patented method of malleableising whiteheart cast-iron with gas instead of the usual hæmatite ore and boxes. The decarburising property of gases used to protect against scaling, normally so objectionable, is put to good purpose in this process. The castings are heated in a constantly renewed or circulated atmosphere which rapidly removes the carbon without oxidising the iron itself. The absence of boxes and hæmatite ore reduces the weight to be heated by two-thirds, and the time required by a still greater amount. The process is clean and easily controllable, and there is a considerable saving in cost.

High-Frequency Heating

Reverting to the general theme, one point that has prevented installation in the line of production is that in many cases a furnace able to deal with a suitable output is inconveniently large for such positions. This difficulty is being surmounted by the advent of a new method, namely, high-frequency heating. High-frequency induction heating has been developed during recent years and especially during the war years, and owing to the rapidity of heating obtainable and the small floor space occupied, it is particularly adaptable to, and suitable for, installation in the main production shop.

In induction heating the heat is generated in the metal itself by the eddy currents induced in it by the current in a surrounding coil. In the case of steel hysteresis also accounts for some of the heat developed, this effect naturally ceasing at the magnetic change point, incidentally bringing about a most convenient slowing down of the rate of heating at the very temperature this would naturally be desired.

The eddy currents are largely confined to the surface layer, the thickness of the layer varying inversely with the square root of the frequency employed, which may vary between a thousand and several million cycles per second. A very high rate of heating can be attained since the heat is generated under the surface and does not have to be passed through it—one of the main factors limiting the rate of heating with radiation or convection methods.

Induction heating may be divided into two classes—surface hardening and through heating.

In surface hardening an extremely high power input is used so that the surface layer of the steel is very rapidly raised to the required hardening temperature. Immediately this temperature is reached the steel is quenched, usually by a water spray from an annular duct, which may itself be the inductor conveying the high-frequency currents, surrounding the part. Where a bar, such as a splined shaft, has to be hardened it is done progressively, the bar moving through the coil so that a ring of heated metal is produced, this being immediately quenched as it reaches the adjacent spray. The thickness of the layer hardened depends both on the rate of heating and the frequency employed, and may readily be varied between wide limits. The heating can be carried out in as short a time as a quarter-of-a-second when using a power input of about 10 kw. per sq. in.

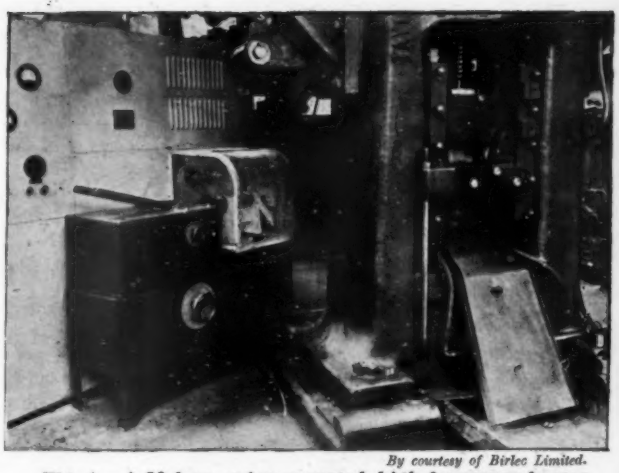
One great advantage of this process is that there is no distortion since the mass of the steel is not heated ; the rapidity of the heating also prevents decarburisation or scaling.

In through heating, as the term implies, the part is heated right through. This is achieved by using a lower rate of heating and giving time for the heat to be conducted into the interior. This process is used for heating small billets for forging, the ends of bars for upsetting, and so on.

Absence of scale, small floor space, and its ready combination with automatic handling gear are a few of the advantages. In many cases the operating costs are less than those with fuel-fired furnaces, but admittedly the capital cost is high. Fig. 6 illustrates a magazine-fed automatic handling unit supplying small billets ready heated for the adjacent press.

Great interest has been aroused by these new high-frequency methods, about which there have been many technical articles, which should be referred to for more detail.

An attempt has been made in this article to indicate a few of the directions in which heat-treatment will probably develop and to show how modern equipment lends itself more readily for use in the line of production, and it is hoped that engineers will be stimulated to investigate these processes.



By courtesy of Birlec Limited.

Fig. 6.—A 20 k.w. valve operated high-frequency heater for small billets with automatic magazine feed.

Ferro-Alloys and Alloying Metals for Foundries and Steel Plants

SILICOMANGANESE is one of a full line of ferro-alloys and alloying metals offered for export to iron and steelmakers by St. Lawrence Alloys & Metals, Ltd., of Beauharnois, Quebec, Canada. This combination alloy of manganese and silicon is more rapid and effective and less costly as a deoxidizing and cleansing agent in steel than separate alloys of silicon and manganese. The use of silicomanganese also results in higher and more uniform manganese recoveries and effects important savings in furnace time. These advantages have made silicomanganese important in the production of quality steels for war munitions and equipment of all kinds.

Refined grades of ferrochrome and ferromanganese are also of particular interest. Because of their extremely low carbon content, these refined alloys are useful for the economical production of low-carbon chromium steels and low-carbon manganese steels, particularly those containing considerable amounts of chromium and manganese. Among the steels in which refined ferrochrome and refined ferromanganese are used to advantage are stainless steels ; heat-resisting high-chromium steels ; high-strength structural, engineering, and tool steels ; magnet steels ; and medium-manganese and high-manganese steels. Refined ferrochrome is offered in grades containing as low as 0·06% maximum carbon and refined ferromanganese in grades containing as low as 0·10% maximum carbon.

Among the newer alloys in steel metallurgy, zirconium is especially promising and already enjoys wide commercial acceptance. Zirconium is a powerful deoxidiser, desulphuriser, and grain refiner, improving such properties as hot-rolling, soundness, shock resistance, deep-drawing, free-cutting, and depth-hardening in many steels. It has, for instance, found considerable use in the production of deep-drawing sheet steel, high-strength structural steel, and light armour plate. Two alloys of zirconium are offered ; 14% zirconium alloy and 40% zirconium alloy.

Of particular interest to iron foundries are ferro-alloys of chromium, manganese, silicon, and silicomanganese in briquet form. These briquets are a convenient and efficient means of adding exact amounts of ferro-alloys in the cupola. A binder protects the alloy from oxidation on its way to the melting zone and releases the alloy in liquid form where it does the most good, thus assuring uniformly high recoveries.

By using these briquets, the foundryman can at will increase or decrease the amounts of steel scrap, iron scrap, and pig iron in his charge, depending on prevailing market conditions, and at the same time obtain a better, more uniform, iron at lower cost. Each of these briquets is of distinctive shape and contains an exact amount of the alloying element, so that the exact alloying additions desired can be easily obtained by counting out and adding the correct number of briquets. Weighing is eliminated.

In addition to those mentioned, St. Lawrence Alloys offers other standard and special alloys of chromium, manganese, silicon, and calcium, and balanced combination alloys for special purposes which contain one or more of these elements together with aluminium, boron, titanium, vanadium, zirconium, and others. All of these alloys are electric-furnace products.

Messrs Chapman & Hobbs have re-opened their offices at Kingsway Corner Building, at 109, Kingsway, W.C. 2. Telephone Nos. Holborn 7145 and 7146. As the London representatives of William Jessop & Sons, Ltd., and J. J. Saville & Co., Ltd., they will be pleased to deal with enquiries for the many specialised lines of steels and steel products produced by these old-established Sheffield firms.

Some Factors Connected with the Heat-Treatment of Magnesium Alloys

By F. A. Fox, M.Sc.
Chief Metallurgist, Magnesium Elektron Ltd.

To make the best possible use of the magnesium alloys it is necessary to be familiar with those whose properties can be improved by heat-treatment and with the treatment which will give the desired result. A number of these alloys have been used to a great extent during recent years and have become familiar to engineers, but many factors associated with their heat-treatment are still imperfectly understood; some of these are briefly discussed.

THE engineering alloys of magnesium in use to-day fall into the following categories :—(*a*) Those in which aluminium is the principal alloying constituent. (*b*) Those in which manganese is the principal alloying constituent.

Of these, only the first are heat-treatable in the ordinary sense of the term. In current British practice heat-treatment is seldom applied to wrought materials and the bulk of the discussion given below centres on the cast alloys.

The cast aluminium containing alloys are those conforming to the following D.T.D. specifications :—

D.T.D. 59A, D.T.D. 136A, D.T.D. 289, D.T.D. 281 and D.T.D. 285.

TABLE I.
THE EFFECT OF HEAT-TREATMENT ON THE MECHANICAL PROPERTIES OF THE ELEKTRON ALLOYS A.8 AND AZ. 91

D.T.D. Spec.	Elektron Alloy	Nominal Composition (about 0·3% Mn. is also present in each case)	Condition	0·1% Proof Stress Tons/sq. in.	Ultimate Stress Tons/sq. in.	% Elongation on 2 in.
59A	A8	Mg+8% Al+0·4% Zn	As cast.. ..	5·3	10·5	3·0
289	A8	Mg+8% Al+0·4% Zn	Solution treated	5·1	17·0	12·5
136A	AZ91	Mg+9·5% Al+0·4% Zn	As cast.. ..	6·0	9·6	1·5
281	AZ91	Mg+9·5% Al+0·4% Zn	Solution treated	6·0	17·0	9·0
285	AZ91	Mg+9·5% Al+0·4% Zn	Solution treated and precipitated	7·5	17·0	1·5

Table I gives indications of the tensile strength changes which are produced by the standard heat-treatments. These mechanical property changes are naturally the accompaniment of important micro-structural changes, the general sequence of which, from the precipitation end, has already been fairly thoroughly investigated.[1] These heat-treatment effects are associated with the usual type of equilibrium diagram showing a curving solid solubility boundary, Fig. 1. The eutectic temperature is 436° C. in the binary diagram and at this temperature a solid solution containing approximately 12·6% of aluminium is formed; this solid solubility falls rapidly with decreasing temperature to about 2·6% at 150° C. In the sand- or die-cast alloys of magnesium and aluminium, small particles of beta phase are produced during solidification when the aluminium content is as low as about 2%.

In the work quoted the precipitation mechanisms were followed and it was found that four general types of precipitate were produced. These are shown in Figs. 2–5. It was found that for a given precipitation treatment a higher aluminium content produced a finer form of precipitate and that the best mechanical properties were obtained when the precipitate was fine. The actual form of the precipitate, however, was not critical.

This work was mainly concerned with material which had had solution treatments which resulted in more or less complete homogenisation. In practice, however, less difficulty is likely to result from the precipitation step than from the solution treatment itself, since it is this which conditions the larger scale homogeneity of the piece.

Effect of Grain Size

In order to obtain a uniform solution treated structure it is desirable to have a grain size in the cast piece which is also as uniform as possible. Further, that uniform grain size should be as small as possible. These two requirements of uniformity and small grain size spring from the same basic consideration—*i.e.*, ease of solution of the beta phase is naturally much greater when it is in fine distribution. If the grain size is large the beta phase network or incipient network is correspondingly coarse and solution treatment is hindered from two points of view :—

(i.) That of the thickness of the beta phase network.
(ii.) That of the relatively larger distances over which diffusion has to take place.

An indication of the influence of grain size on rate of homogenisation can be obtained from a consideration of the following result which was obtained on Elektron A. 8 :—

A chill cast "pencil" (of the type used for spectrographic test purposes) 7 mm. in diameter was selected as representative of sections which for practical purposes would have the smallest grain size, and a small experimental billet, 4 in. dia. × 6 in. long, which had been slowly solidified in a furnace, as representative of the largest section likely to be used in casting work. These two specimens showed a ratio in grain size of about one to twenty, the spectrographic "pencil" having an average grain size of 0·04 mm., and the furnace cooled billet, 0·75 mm. Figures 6 and 7 show the respective "as cast" structures.

The spectrographic test casting mould in which the "pencil" sample was cast was at a temperature of about 250° C., the casting temperature was 730° C. The rate of cooling of the small billet was about 100° C. per hour over the range 750° C –300° C.

[1] Fox and Lardner, *Journal of the Institute of Metals*, 1943, Vol. 69, p. 373.

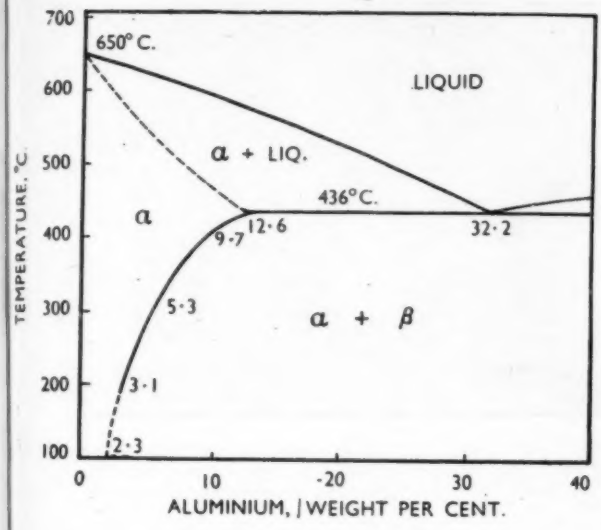


Fig. 1.—Equilibrium diagram for magnesium-rich magnesium-aluminium alloys.

A number of specimens cut from each sample were given heat-treatment in SO_2 at 415° C. until solution was complete, and examined periodically during the treatment to determine the degree of solution obtained.

The beta-phase in the spectrographic " pencil " completely disappeared in 18 hours, but that in the 4 in. × 6 in. billet section completely disappeared only after 300 hours soaking. Fig. 8 shows the structure of the billet section after 192 hours soaking.

Commercially solution treated castings are seldom free throughout from the presence of the beta-phase : at the same time they should be much more free from it than is the structure shown in Fig. 8

This test, therefore, emphasises the necessity for small grain size in all parts of a casting : it must not be supposed that if a casting is to be solution treated, its " as cast " grain size is of less vital importance.

The way to achieve a fine grain of this kind in the aluminium containing magnesium base alloys is by using the well-known superheating process, which involves close control of time and temperature of the charge during the period when it is molten. The mechanism of the superheating process is not yet understood although a certain amount of work has been done on it.[2]

Effect of Aluminium Content

Additional to the question of grain size as influencing the rate of homogenisation, the question of the aluminium content of the alloy is naturally also involved. The most marked effect of an increasing aluminium content is shown in Fig. 9 from which it can be seen that at aluminium contents corresponding to the range covered by D.T.D. 136A, small increases in aluminium content may cause a large increase in the time required to solution treat the alloy to produce a structure which is microscopically homogeneous. Thus, increasing the aluminium content from 9·5% to 10·0% increases the time required for complete solution from 42 hours to 68 hours, whilst a further increase to 10·5% would increase the time required to about 150 hours. The data in Fig. 9 were obtained on sand-cast test bars made under conditions as standard as possible, with good superheating and fluxing practice. The grain sizes were all of the order of 0·1 mm. The criterion of perfect solution adopted in these tests was fairly stringent and was considerably more rigorous than that required for control of commercial practice.

However, it does seem to be the case that even where only relatively small quantities of beta-phase remain in the solution treated material the mechanical properties are adversely effected to a definite though not large extent. Fig. 10 shows the structure of an alloy which has been solution treated (imperfectly) and then precipitation treated. The residual beta-phase is clearly shown

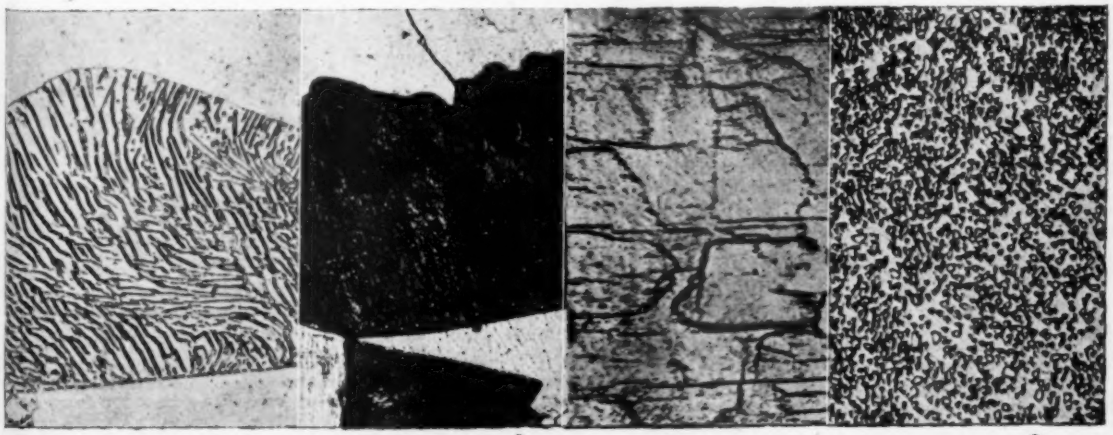
[2] Fox and Lardner, *Journal of the Institute of Metals*, 1945, Vol. 71, Part I, p. 1.

Fig. 2.—Microstructure of 8% aluminium alloy, solution treated and quenched, and precipitation treated for 3 hrs. at 250° C., showing " pearlitic " structure. × 600.

Fig. 3.—Microstructure of 8% aluminium alloy, solution treated and quenched. Precipitated 80 hrs. at 130° C. Showing " troostite" structure. × 600.

Fig. 4.—Microstructure of 8% aluminium alloy, solution treated and quenched. Precipitated 6 hrs. at 150° C. Showing " mosaic outline " structure. × 600.

Fig. 5.—Microstructure of 12% aluminium alloy, solution treated and quenched. Precipitation treatment 72 hrs. at 250° C. Showing "spheroidite" structure. × 600.



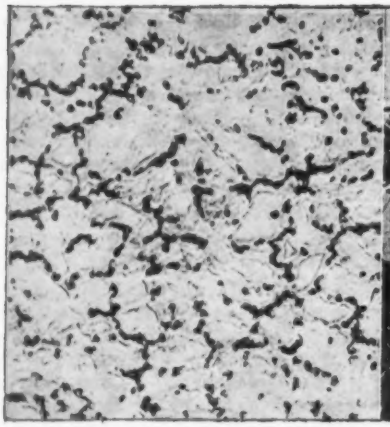


Fig. 6.—Elektron A.8 chill cast spectrographic "pencil," 7 mm. dia. Average grain size = 0.04 mm. × 300.

Fig. 7. Elektron A.8 slowly cooled in furnace. Average grain size = 0.75 mm. × 300.

Fig. 8. Elektron A.8. 4 in. × 6 in. billet cooled in furnace. Structure after 192 hours at 415°C. × 300.

up as white "stringers" in the grain boundaries. This quantity of beta-phase is beginning to be sufficient to have an adverse effect on the static mechanical properties of the solution treated material.[3] As far as the author is aware no data has been published on the influence of small quantities of residual beta-phase on the fatigue properties of solution treated material, but such effects might be expected also to be harmful.

The influence of residual beta-phase on material which is to be precipitation treated is not, however, by any means, so critical, at least as far as the static mechanical properties are concerned. The reason for this seems to be that the general strengthening effect produced by the precipitate masks the local embrittling effect which the beta-phase can exert on the structure when present in an unprecipitated matrix, which is otherwise homogeneous. The differences between the static mechanical properties of precipitated material containing no massive residual beta-phase, and of otherwise similar material but containing residual beta-phase similar in amount to that represented in Fig. 10, is negligible as determined by a large number of tests with sand-cast D.T.D. type bars.[3]

Temperature of Solution Treatment

In view of the fact that solution treatment proceeds so much more rapidly if the temperature can be even slightly elevated, it has sometimes been suggested that addition of small amounts of calcium to the aluminium containing alloys are desirable. It is claimed that calcium additions particularly when made to alloys containing 1–3% zinc increase the inter-granular fusion temperature and so make possible the use of higher temperatures for solution treatment, with a consequent shortening of process times.[4] The question as to the desirability of calcium additions ha been investigated.[5] The tests carried out showed that additions of calcium to alloys of the Elektron A. 8 type and to alloys containing 6% aluminium, 3% zinc, do increase the incipient fusion temperature, but in both alloy types, have a retarding effect on the diffusion of aluminium.

For Elektron A. 8 type alloys, however, the diffusion-retarding effect of calcium additions of up to 0·13% has been found to be markedly offset by the possible use of single-step high temperature solution treatments, and the resultant times for the attainment of a fully solution-treated structure are less than the present generally standard solution treatment time of 24 hours. At first sight, therefore, the high temperature short-time treatments appear attractive; they cannot, however, be recommended, because of the distortion by sagging which is liable to occur, particularly for complicated castings with thin sections, when the solution treatment temperatures are in excess of the present standard maximum of 420° C. Since the two alloys are closely similar in general properties, it can be taken that this will be true for Elektron AZ. 91 type alloys also.

For alloys of the 6% aluminium, 3% zinc type, solution-treatment temperatures are necessarily appreciably lower than those for Elektron A.8 type alloys (because of the influence of zinc in reducing the eutectic temperature) and at temperatures in excess of the maximum permissible for the calcium-free alloys, the times for

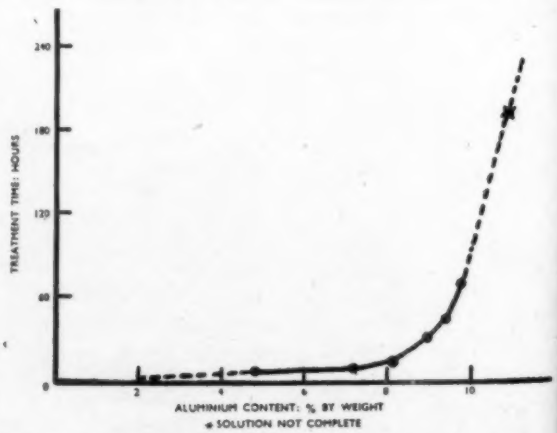


Fig. 9.—Solution treatment of magnesium-aluminium alloys: effect of aluminium content on time for complete solution.

[3] As yet unpublished results.
[4] American Patent No. 2185452.
[5] G. Goddard.—"Some Experiments on additions of Calcium to reduce solution treatment times for Magnesium Alloys," *Magnesium Review and Abstracts*," Vol. 3, No. 4, p. 83.

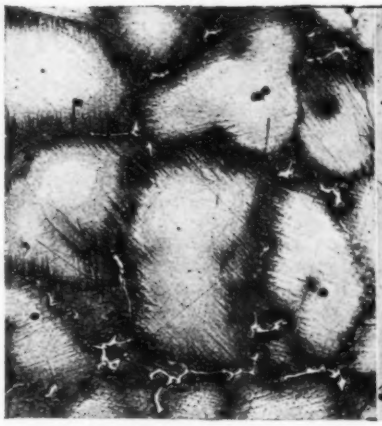


Fig. 10.—Structure of a magnesium-aluminium-zinc alloy, solution treated and precipitation treated, showing considerable quantity of residual beta phase. × 125.

Fig. 11.—Magnesium-aluminium-zinc alloy showing typical structure of solution treated alloy in which incipient fusion has taken place. × 125.

full solution of the calcium containing alloys are still of the order of 20–24 hours.

Fig. 11 shows the micro-structure of a magnesium-aluminium-zinc alloy which has been overheated in solution treatment. This shows the typical structure of an alloy in which incipient fusion has taken place. The second phase has been drawn out along the grain boundaries into charactistic concave sided forms, and elongated voids can be seen.

Direct Precipitation Treatment

It has been proposed[6] to precipitation treat as-cast magnesium alloy without first going through the solution treatment stage. The theory is that advantage could be taken of the hardening effects of such precipitation as can be made to occur in the alpha solid solution, which is super-saturated with beta-phase, since, being a cast material it is not in equilibrium. Precipitation of a material corresponding to D.T.D. 136A at 200° and 220° C. does result in a slight increase in the 0·1% proof stress and U.T.S. values. The elongation also drops slightly on precipitation treatment although this decrease is not marked at 200° C. The improvements in mechanical properties obtained by such a direct precipitation treatment are, however, small as is indicated by the average test data shown below.

Alloy	State	0·1% P.S. t.s.i.	U.T.S.	E % on 2 in.
D.T.D. 136A ..	Sand cast	5·6	9·4	2·0
D.T.D. 136A ..	Precipitation treatment–12 hours at 200° C.	6·1	9·4	1·5
D.T.D. 136A ..	Precipitation treatment–12 hours at 220° C.	5·9	10·1	1·5

The differences shown in the table above are within the range of scatter normally expected in testing magnesium alloys.

Annealing and Stress Relief

The aluminium containing magnesium base alloys undergo a small volume change when they are heat-treated. This change is negligibly small for the lower aluminium content alloys, but becomes perceptible when the alloy contains more than about 8·5% aluminium. The change is in the direction of a contraction on solution treatment followed by an expansion on precipitation treatment. The solution treated alloy containing about 9·5% aluminium expands approximately 0·0008 in. per in. when subjected to a full precipitation treatment at 150°–200° C. With the as-cast alloy the expansion on similar precipitation treatment is approximately 0·0003 in. per in., although this varies somewhat according to the degree of "pearlite" precipitation which may have already taken place in the casting operation.

If a component in—say—D.T.D. 136A is exposed to an elevated temperature in service it may be that the volume change described above, if not properly taken care of would have a harmful effect. It is, therefore, desirable in these circumstances to ensure that the volume change which would occur in service is made to occur in the piece before machining and putting into use. This can readily be done by an "annealing" operation which will also have the effect of relieving casting stresses which, in magnesium alloys as well as in many others, can be quite severe. Alloys of the D.T.D. 136A type are, therefore, frequently given annealing treatments which fulfil this dual purpose. Any treatment in the temperature range of 250°–320° C. will produce good results. The stress-relieving effects naturally occur much more rapidly as the temperature is raised and the precipitation changes which produce the dimensional alterations are also finished more rapidly. An annealing time of about four hours in this temperature range is usually sufficient to remove both the internal stress and the volume change tendency.

For these reasons annealed cast material has been increasing in popularity for parts which are exposed to elevated temperatures—*e.g.*, engine components; this is particularly the case where material corresponding to D.T.D. 136A is used.

With regard to wrought materials, the same general considerations apply as those which have been described for the cast alloys. The constitutional changes taking place are naturally, however, more rapid since this is characteristic of wrought materials.

[6] British Patent No. 536407.

Major T. G. Bird, D.S.O.

It is with regret that we learn of the death of Major T. G. Bird, D.S.O., on 7th May, 1945.

Major Bird had been associated with Sir W. G. Armstrong Whitworth & Co., Ltd., for the last 25 years and latterly was managing director of Sir W. G. Armstrong Whitworth and Co. (Ironfounders), Limited, and the companies of the Jarvis Industries Group, under the chairmanship of Sir John Jarvis, Bart., M.P., D.C.L.

The British Aluminium Co., Ltd.—The Manchester Office is located temporarily at Chancery Chambers, 55, Brown Street, Manchester, 2. Telephone No.: Blackfriars 8913. Telegrams: "Aluminium, Manchester." The Branch Manager is Mr. J. R. Whitelegg.

Hard Surfaces on Steel by Induction Heating

By J. L. Aston

High-frequency induction heating has been applied to the heat-treatment of parts during recent years. The rapidity of heating and the small floor space necessary makes this form of heating especially applicable for use in main production shops. Induction heating is applied for surface hardening or a lower rate of heating is applied so that the part treated may be heated throughout. Progress in this important branch of heat-treatment in its application to the production of hardened surfaces is reviewed.

DURING the last ten years the method of locally heating steel parts by induced electric currents has passed from the laboratory to the production line. The principles of induction heating were understood at the end of the last century, but it was not until about 1935 that the method was developed, in America and Russia, for general commercial use. Since then it has become deservedly popular in both countries, and is now being developed rapidly elsewhere, especially in this country and in Australia. Strangely, little has been heard of local induction heating in Germany.

While induction heating finds many other uses, as in brazing, melting and heating for forging, its most revolutionary application is to the local hardening of steel parts. This method of heating makes it possible to bring the surface of a steel bar to 850° C., while a point 1 mm. below the surface is not hotter than 200° C. If the whole bar is then quenched, the surface will be given the maximum hardness attainable in that particular steel, while the structure and properties at a depth of 1 mm. and more will remain unaffected. The heating and quenching are generally completed in 1–10 secs., and in this brief time no scaling occurs, merely a slight tarnishing. It is therefore possible to finish-machine a part while it is still comparatively soft, then for an unskilled operator to surface harden where necessary with great speed and negligible oxidation and distortion.

This method has been applied to practically all those parts which have been treated in the past by the slow and wasteful method of pack carburising—crankshaft journals, cams, gudgeon pins, gears, gauges, etc. Induction hardening is, however, more than a new way of obtaining an old result. It makes it possible to obtain results which were not possible before. This has already been proved many times in the field of brazing by induction heating, and the immense value of being able to finish-machine to close limits, and then to surface harden, is now becoming widely realised, especially in gear-making.[1]

For local inducting heating, a generator of high-frequency alternating power is required. The current from this is passed through a coil of water-cooled copper tubing surrounding the particular section which it is required to heat. This produces heating of the work in two ways, firstly by reason of the current induced in the work, and secondly (if the part is ferro-magnetic) by reason of the alternating magnetisation of the specimen.

1. *Eddy Currents.*—If a conductor is wrapped round a metal bar and carries an alternating current, alternating currents will be set up in that bar and will tend to flow in a direction parallel to that of the current in the surrounding conductor. These currents are known as "Eddy" or "Foucault" currents.

Unless the frequency of the alternating current is quite low (20 to 1,000 cycles per sec., depending on the material) the current will not be uniformly distributed over the cross-section of the bar, but each "filament" of current will repel every other "filament" in a direction perpendicular to its length. Hence the current will tend to be densest along the sides of the bar, and will be somewhat as indicated in the sketch, where density of shading represents current density and direction of shading shows the direction of the eddy currents.

The current density falls off exponentially towards the centre of the bar, i.e., it decreases by an equal percentage of its local value at every point below the surface, and since the heating effect is proportional to I^2R (I = current, R = resistance), the rate of heat production falls off even more rapidly towards the centre. The current has dropped to $1/e$ of its surface value at a depth of—

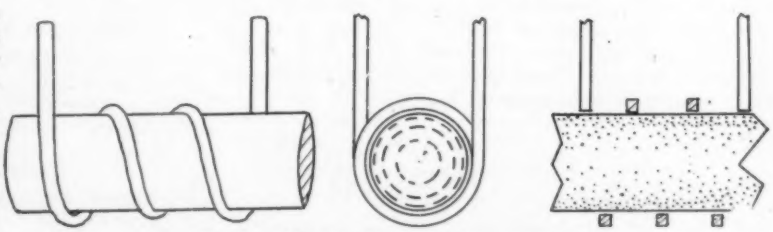


Fig. 1.—Distribution of eddy currents.

$$p = \frac{1}{2\pi}\sqrt{\frac{\rho 10^9}{f\mu}}$$

$$= 5{,}030\sqrt{\rho/f\mu}$$

where ρ = specific resistance of the material treated, ohms., cms.; f = frequency; μ = permeability of the material, and is unity for non-magnetic material.

It can be shown in theory, and verified in practice, that at any instant 35% of the eddy current effect and

1 G. C. Riegel. *Metal Progress*, 1943, **44**, p. 78.

85% of the heating effect are concentrated in a peripheral layer of this thickness.

(2) *Magnetic Hysteresis.*—In addition to the heating due to eddy currents, there is an additional heating of the work due to an entirely magnetic phenomenon. If a bar of magnetic material is placed in an alternating magnetic field, as, for example, that due to a coil carrying a current, then the specimen will be demagnetised, and remagnetised in the opposite direction, at every reversal of the field. As the molecular magnets have to rearrange themselves at every remagnetisation, there is a good deal of internal friction (hysteresis) and heat is therefore developed.

At frequencies less than about 100 kcs./sec., for bar steel at normal temperatures, the hysteresis effect is somewhat more important than the eddy-current effect, but above that frequency the eddy-current effect increases rapidly in relative importance. This is because, other things being constant, the power developed by eddy-currents is proportional to the square of the frequency, whereas the hysteresis loss is proportional to the first power of the frequency. However, as the steel heats up, whatever the frequency, the importance of the eddy current heating increases while that of the hysteresis heating decreases.

Since the power dissipated in the specimen rises with the frequency, while the depth of penetration falls as the frequency is raised, the concentration of energy in the surface of the work increases rather rapidly with frequency, provided that the necessary power input can be maintained.

For pure metals, the specific electrical resistance is roughly proportional to the absolute temperature, and while this rule does not hold even approximately for alloys, it is still true that the resistance of most metals, including carbon steel, increases with temperature. As a result of this, with rising temperature the depth of heat penetration increases rather slowly, while the rate of heat development increases rapidly.

For carbon steel at 20° C., the depth of penetration at frequency f is $20/\sqrt{f}$ mms.[2] As the steel heats up, the resistivity increases and the permeability decreases slightly, with the result that the power input to the metal, and also the depth of heating, increase. However, at the Curie point (A_{c3}) the steel becomes non-magnetic and the permeability drops to unity, so that the depth of penetration then becomes $500/\sqrt{f}$ mms.—i.e., about 25 times the depth in cold steel.

Since the heating effect is initially greatest at the surface, the surface first reaches the Curie point, but the thickness of metal above this temperature is quite small. However, as the surface is now non-magnetic the average depth of heating becomes a little greater, and in addition the surface heats up much more slowly than before. In this way the heat is produced deeper and deeper as time goes on, and as more and more of the steel reaches a temperature from which it will quench-harden; but the surface will not overheat considerably as less heat is being dissipated in it. This is one of the great advantages of induction hardening over flame-hardening, in which the inner parts of the metal can only heat up if they are considerably cooler than the surface, and the latter is therefore liable to serious overheating if a deep case is required.

The depth of the heated layer may be greater at any instant than the theoretical depth of penetration of eddy currents since heat is rapidly carried towards the centre of the specimen by thermal conduction. When the frequency is such that the depth of penetration is considerably less than the thickness of the layer to be hardened (depth $\times \sqrt{f}$ greater than 1,000), conduction is of main importance in controlling the power input and heating time. However, when the required depth of case is less (depth $\times \sqrt{f}$ less than 500), the specific heat of the steel is of primary importance.

2 G. Babat and M. Losinsky. *J. Inst. Elec. Eng.*, 1940, **86**, p. 161.

High-Frequency Generators

	Rotary Generators.	Spark Gap Oscillators.	Thermionic Oscillators.
PRINCIPLE	Power is supplied to an electric motor which drives a dynamo constructed to give the required frequency.	A large alternating voltage from a transformer is applied across a spark gap. Each time there is a spark, a series of oscillations is set up in a resonant circuit which includes the gap.	Similar to the oscillators of radio practice. Generally of the Hartley type.
POWER OUTPUT	In regular use up to 500 kw. Limited only by mechanical strength.	Limited by the power the gap can control. Generally less than 40 kw.	Limited by the valves available. Generally less than 100 kw.
FREQUENCY ATTAINABLE.	Not more than 10 kcs.	Generally 50–200 kcs.	Not normally used below 100 kcs. Available to at least 20 mcs.
EFFICIENCY ...	60–80%.....	20–50%.....	40–50%
MAINTENANCE .	Purely mechanical	Gaps need regular (weekly) attention.	Valve life about 10,000 hours.
COOLING	Air or hydrogen...	Gap electrodes water cooled.	Air or water depending on power output (below or above about 20 kw.)
REFERENCES ..	3, 4	3, 4	3, 5

Rotary Generators.—Mechanical generators have been widely used in America, but very little elsewhere. The fact that fairly high frequencies are unobtainable is a very severe limitation for certain types of work, in particular for small parts and for parts of complicated section. In other ways, too, this type of generator is rather inflexible. In order to maintain a good power-factor to it it is usual to have a series of condensers in parallel with the work-coil, these being automatically switched into the circuit one at a time during the heating cycle by means of a series of cam-operated switches.

This type of generator is extremely noisy, but since it is possible to conduct the power over distances of up to 200 yds., this is not important, as the generators may be grouped together in a special power-house.

Spark-gap Oscillators.—This method is not so widely used, owing to the low efficiency and to the need to reface the spark-gap pole-pieces every 40 to 50 hours. It has been applied mainly to the surface hardening of very small parts, as in typewriters and calculating machines, where a high frequency is essential, and the low efficiency and power output is less important. The spark is usually in air, between water-cooled tungsten pole-pieces, but it may take place in an inert gas or in a liquid.

Thermionic Oscillators.—This method has been used almost exclusively in Russia, where much of the published work on induction heating has been carried out, and is being developed in this country. It is the most adaptable system and is capable of much higher frequencies than either of the other methods. The main difficulty lies in the rather small power of the sets so far obtainable, although the Russians are using installations with an output of more than 200 kws.[6] The equipment is capable

3 A. L. Simmons. *Australasian Engineer*, 1943, **43**, p. 18.
4 "Fundamental of Induction Heating." Data Sheets. Induction Heating Corporation, New York, U.S.A.
5 L. L. Langton. *Wireless World*, 1944, **50**, p. 70, 111, 137 and 179.
6 G. Babat and M. Losinsky. *J. App. Phys.*, 1940, **11**, p. 816.

of fairly high efficiency, and, in addition, it presents a power factor of at least 0·9 to the supply.

Two types are in use, those in which power is taken direct from the tuned circuit of a self-excited power oscillator valve, and those in which a master oscillator circuit (normally a valve oscillator) drives an independent power amplifier valve. The former type is self-tuning, whereas the latter will require retuning for even small changes in the heater circuit and work-piece.

The design of power oscillators, with especial reference to those operating in push-pull under Class "C" conditions, has been touched on by L. L. Langton.[5]

Supplementary Equipment

While the generation of large, high-frequency alternating currents presents a problem of interest to the electrician, the metallurgist is more concerned with the conversion of those currents to heat in the surface of the work-piece. For this, a well-designed coil is essential, and for maximum success a concentrator or screen may be required if the work is of complicated shape or if it is necessary to define accuratly the limits of the heated zone.

Design.—The design of this equipment, necessary for transferring power from the generator to the parts of the work which it is required to heat, is mainly a matter for intelligent trial, based on previous experience, although the theory has been worked out in very simple cases.[7, 2] A few articles have been published which suggest the vast variety and range of coils which may be required.[8, 9] However, in order to facilitate design, two fairly simple methods have been suggested for testing the effect of particular layouts without the need for detailed metallurgical examination, and, in one case, without even building the proposed coil.

G. Babat and M. Losinsky[6] have described a method of determining, by means of an electro-static model, the high-frequency field in the vicinity of the specimen with some particular experimental design of inductor coil, and of concentrator and screen if used. It depends on the analogy between the magnetic field around the work and the current lines around models of the heater coil and part, when the latter, made of di-electric, are placed in an electrolytic tank so as to represent their proposed relative positions in space. The design may then be varied in the model until a satisfactory arrangement is found, without the trouble and expense of making up a number of coils and concentrators.

The temperature distribution over the work resulting from particular experimental conditions may be investigated by means of heat colours, by heating for a shorter time than usual, or with a reduced power. The specimen may then be repolished and used with another coil, the results being compared by means of photographs or diagrams of the colour distribution. Instead of relying on temper colours, use might be made of one of the proprietary paints, which change colour at a definite temperature. To trace temperature distribution within the piece, a specimen may be used consisting of lamellæ. Provided that the laminating planes are perpendicular to the magnetic flux, the distribution of eddy currents will be the same as within an entire specimen. After heating, the specimen may be taken apart, and then the depth of heat penetration may be determined.[8]

7 Burch and Davis. "An Introduction to the Theory of Eddy-Current Heating." Benn. 1928.
8 G. Babat. *Heat Treating and Forging*, 1941, **27**, pp. 39, 89, 137, 192.
9 F. W. Curtis. *Machinist*, 1944, **87**, pp. 83 and 94; and **88**, p. 91.

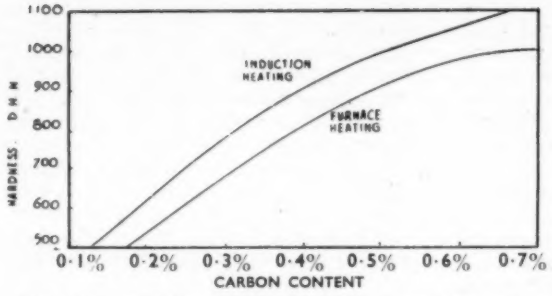


Fig. 2.—Hardness obtainable with a varying carbon content.

Inductor Coils.—Inductor coils are almost always constructed of water-cooled copper tubing, which may be of square or circular section. The square section has slight theoretical advantages, but in practice, cylindrical tubing is easier to manipulate. The wall thickness of the tubing should be not less than about three times the depth of penetration of the current in copper at the frequency in use, which is about $50\sqrt{f}$ mms. (f = frequency, cycles/sec.). This is in order to keep the ohmic resistance of the copper, and hence energy losses in it, as small as possible. Despite this restriction, it is still possible, if adequate water pressure is available, to use tubing of as little as $\frac{1}{8}$ in. external diameter, with a frequency of above 100 kilocycles.

G. Babat has provided[8] a large number of suggestions with regard to the design of inductor coils for the overcoming of various difficulties. For instance, the problem of a shoulder which tended to overheat was solved by using a larger coil, mounting the work eccentrically, and rotating it. He also suggests methods of overcoming irregularities in heating caused by oil-holes in crankshafts. One method is to insert a small copper plug. Coil design to give uniform heating near grooves, in a tangential or axial direction, is also discussed.

To obtain uniform heating right along the curved surface of a cylindrical specimen, the height of the heater coil should be $h - 2a$, where h is the axial length of the cylinder and a is the clearance between the cylinder and the heater coil.

Concentrators

(1) *Space-filling Type.*—It is sometimes not possible, owing to the shape of the part to be heated, to make the clearance between it and the coil small all the way round. This is liable to reduce the coupling considerably, and therefore to reduce the efficiency of energy transfer. However, a non-magnetic metal placed in this space appears to exclude the field from the volume that it occupies, and hence concentrates the lines of force elsewhere.[3]

(2) *Transformer Type.*[6]—It is not possible to have large voltages between successive turns of the heater coil, or thermionic emission from the heated work will cause a breakdown of electrical insulation. In order to use a multi-turn coil and still to have the concentrated field of a single-turn coil, a transformer type concentrator is used. It consists of a massive copper bushing, slotted, and surrounded with a large coil. Eddy currents flow on the surface facing the multi-turn coil, along the sides of the slot, and close themselves on an internal crest which faces the piece to be treated. Since the crest is considerably less in height than the surface facing the

heater coil, the density of eddy currents on the crest will be very large. The magnetic field of greatest intensity will therefore be in the space between the crest of the concentrator and the work-piece.

Screens.—Copper screens may be used to prevent some sections, which it is not required to treat, from heating, when it is impossible to keep the coil away from them—e.g., the webs of crankshafts. Screens must be continuous, to form a closed circuit for eddy currents, and not slotted, like concentrators.

Concentrators and screens are generally made of copper sheet, shaped to follow closely the profile of the coil and of the section of the work which is to be heated or protected, as the case may be. For maximum efficiency the thickness of the copper should be not less than three times the theoretical depth of penetration of current in copper. Although copper heats only about one-thirtieth as much as steel, it may be necessary to cool the concentrator.

Cores.—In order to decrease the magnetic resistance of part of the path of the magnetic lines of force, laminated cores of magnetically soft material are sometimes used, although this is not generally possible at frequencies of more than about 10 kcs. However, dust-iron cores may be used for rather higher frequencies, although the increased power loss is liable to offset any gain. To increase the heating effect at the end of a coil, and to reduce the usual falling-off in flux density there, an iron core may be placed in contact with the end of the work-piece. In addition, cores are often placed inside coils which are to be used for the hardening of internal surfaces.

Applications of Surface Hardening

Very many examples of local heating by induction, followed by quenching, have been described,[10, 11, 12] the best known application being to the hardening of the bearing surfaces of crankshafts.[13, 14, 15]

This method of treatment has also been applied to the surface hardening of gears, with a considerable economy in machining and in case-hardening costs. No grinding is necessary, as the gears are hardened after shaping with no increase in the surface irregularities. In addition, as there is no shaping operation after hardening, a considerably higher hardness may be used, and this will enable the gear to carry more power.[16]

A description has been given[1] of the difficulties encountered and overcome in the treatment of a gear 25·7 in. in diameter with a 5-in. face. The gear is given a sorbitic structure before machining, and is preheated to 300° C. for induction hardening. Induction heating takes 90 secs., and there is then a delay of 14 secs. before the beginning of the quench, in order to prevent too rapid a transition between the core and the case. Finally, the gear is tempered at 150° C. for one hour to relieve stresses. The product obtained in this way was far superior to anything which could be obtained by traditional methods.

Progressive Hardening.—Parts longer than about ten times the diameter are generally heated and quenched progressively. They are passed through the heating coil and then through a quenching spray, the speed being such as to allow the surface to reach hardening temperature during the time spent in the coil. The axial length of the heating coil should not be less than about ten times the thickness of the required case.[2]

An alternative method for long parts of uniform section is to pass the generated current through the work, without using an inductive coupling.

Internal Hardening.—In general, this requires the coil to be inside the work, and heating is by the external field of the coil. The coupling is therefore poor, and it is necessary, in order to attain satisfactory efficiency, to have a very small clearance between the coil and the work. In addition, the resistance of the return magnetic path through the centre of the coil must be kept as small as possible. It may be decreased by using a core of ferro-magnetic material. Laminations cannot be used above about 10,000 cycles, although dust cores should be possible up to much higher frequencies.[8] The core material must have a high Curie point, as it will be heated by its own resistance and hysteresis, and also by radiation from the work. An iron-cobalt alloy is frequently used.[3] When a core cannot be used, owing to the frequency, the diameter of the free space inside the coil should be kept as large as possible, to reduce the resistance of the magnetic circuit, and to prevent heating of the inner parts of the coil.[8]

Internal progressive heating has been extensively used in America for the hardening of cylinder liners.[17] In this case, the coil is slowly raised up the inside of the liner and is followed by the quenching spray.

The inner surfaces of slotted dies and other slotted tubes may be heated by a coil external to the work, since the slot prevents the eddy currents from closing on the outer surface, and therefore they pass along the slot edges and close on the inner surface of the die or tube.[2, 8]

Through Heating.—Parts may be readily heated right through by induction, for either quenching or annealing. While the total energy efficiency of the system is at least ten times as high as for furnace heating, the high initial cost of the installation has prevented its wider use.

Metallurgy of Induction Hardening

Steels Suitable for Induction Hardening.—Practically any steel which will quench-harden will induction harden, and in most cases will give a higher hardness than when the same steel is furnace heated.

F. W. Curtis suggests[11] that a high-tensile free-cutting steel (e.g., carbon 0·40%, manganese 1·5%, sulphur 0·1%) would be very useful for induction hardening. The manganese and sulphur in this steel would give it excellent machinability, far better than in a plain carbon steel of 0·40% carbon. As far as can be determined, the manganese and sulphur do not have any effect on hardenability when induction heating is used.

Where even greater surface hardness and strength are required, a suitable composition would be: Carbon, 0·50–0·60%; manganese, 1·5%; sulphur, 0·28%. This steel would be easily machined, and would fully harden by induction to about 900 D.H.N., or about 700 D.H.N. after a low-temperature temper for the purpose of removing quenching strains.

Previous Treatment.—The previous heat-treatment is dictated by the properties desired in the core, and will generally consist of hardening and tempering. The structure provided by this treatment is very suitable as a preliminary to induction hardening, owing to its

10 R. Legrand. *Machinist*, 1943, **86**, pp. 1079 and 1158.
11 F. W. Curtis. *Steel*, 1943, **112**, pp. 76 and 117.
12 T. E. Eagan. *Industrial Heating*, 1943, **10**, p. 1282.
13 *Engineering*, 1940, **150**, p. 426.
14 A. D. Assonov. *Vestnik Metallopromyshlennosti*, 1940, p. 61.
15 *Iron Age*, 1941, **148**, p. 69.
16 F. W. Curtis. Amer. Soc. Tool Eng., *Tool Engineer*, 1942, Oct.
17 H. B. Somes. *Electrochemical Society*, 1941, **79**, p. 45.

fineness.[3] However, even a fully annealed structure may be hardened, since diffusion has been found to take place extremely rapidly.[18] It has even been suggested that valuable results might be obtained by quenching sooner than has previously been found possible, when no change has taken place except that from α-iron to γ-iron.[19]

Carbide Diffusion in Heated Specimen.—Experiments in which furnace heating has been used have shown that carbide diffusion, even from comparatively coarse pearlite, is able to go to completion in 0·1–0·2 secs.[18] Even shorter times are sufficient with induction heating, a total heating time of 0·2 to 0·3 secs., only a part of that time above the critical range, having been sufficient to allow diffusion to take place. Considerable hardness can be attained, even if the temperature does not reach the A_{C3} point. This rapid diffusion with induction heating is generally attributed to the carbide heating up more rapidly than the ferrite owing to its higher resistance, but no evidence has been offered in support of this explanation.

Since the pearlite-austenite transformation takes place so rapidly, and mainly in the critical range, a great deal of free ferrite might be expected. In actual fact, however, although it is the carbide areas which are first transformed, a fine, fully homogeneous, structure is formed almost immediately afterwards and is retained in quenching.

Resulting Structure.—The usual acicular martensite resulting from conventional methods of heating is usually absent. Instead there is a more homogeneous structure : a nodular martensite of greater fineness. This fine structure is produced from an austenite which is the result of a more thorough carbide diffusion than can be obtained with thermal heating, and is more apparent with plain carbon steels, because of the nodular appearance of most alloy martensite.[20]

Many micrographs[17, 18, 21] and macrographs[2, 6] of specimens inductively hardened have been published. Specimens inductively heated show a very small grain size in the hardened area. It appears that in addition to the normal grain refinement resulting from heating past the A_{C1} point, and the very small time available for grain growth, there is an additional refining process, possibly due to the large electro-magnetic forces involved.

Distortion.—As with any other method of hardening, there is a considerable volume change of the part hardened, since the density of martensite differs from that of sorbite or pearlite. However, when the hardened layer is thin compared with the backing layer which has not been affected, there will be very little change in shape or size, although very large forces will be set up in the surface. When the hardened layer is sufficiently thick in relation to the unaffected layer to produce distortion, this distortion will be constant in all parts of the same shape and size treated under similar conditions, and may therefore be allowed for when the part is being machined to size previous to induction hardening.

Hardenability.—Steels inductively surface-hardened appear to have a higher hardenability than when furnace hardened, owing to the fact that the cool centre conducts heat away from the surface which is being quenched, instead of conducting heat to it. as happens when the work has been heated right through. In fact, a steel may be induction hardened to a depth greater than its critical diameter (H. B. Osburn, jun., in discussion of[21]).

In some cases the hardenability of a steel intended for induction hardening appears to be critical, in particular in the case of large gears,[1] where it was specified as between 40 and 47 Rockwell inches. The tendency of a steel of high hardenability to crack at the roots of the teeth was reduced by preheating the whole gear to 300° C. before induction hardening, and this also helped to prevent warpage. A low hardenability may render the steel incapable of the required case-depth.

Attainable Hardness and Super-hardness.—A number of graphs have been published showing the relation between maximum attainable hardness and carbon content for induction heating and for furnace heating.[3, 18]

Water-quenching an induction heated part gives a higher hardness than quenching a similar steel after furnace heating, even though in the latter case it is quenched in iced caustic soda solution. Any lesser hardness for a given carbon content may be obtained by delaying the quench, or by tempering, by induction or otherwise.

Several explanations of the super-hardness attainable by induction hardening have been offered. It may be due to the extremely homogeneous austenite resulting from the rapid carbide diffusion and the attendant small grain size[18] ; or it may be due to internal strains set up owing to the rapid cooling with a backing of unaffected metal.[3] In support of this suggestion, it is stated that tempering at between 100° C. and 200° C. reduces the hardness of an induction treated specimen to little more than that of a furnace hardened specimen of the same material similarly tempered.

Depth of Case.—The surface hardness is maintained for 80% of the case depth, and from there inwards falls off smoothly, through a transition zone, to the unchanged interior of the material.[6, 10, 21] Owing to the gradual transition, no trouble seems to have been experienced from spalling. The case-core transition zone is smaller the more rapid the heating, since conduction tends to enlarge it.

With low power-input per unit area, there is an optimum case depth, owing to the metallographic limitations of incomplete carbide solution for shallower depths and grain growth and coarsening for greater depths. Both of these are accompanied by a fall in surface hardness. The rate of increase of case-depth with heating time is nearly constant when the surface has reached the hardening temperature, and the surface hardness begins to fall off at about the same time or soon after. With high specific power input, the danger of grain growth is much reduced, owing to the shorter

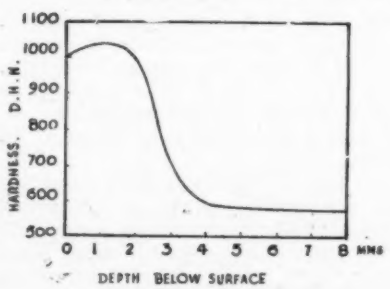


Fig. 3.—Hardness distribution through the case for a 0.55% carbon steel.

18 H. B. Osburn, jun. *Electrochemical Society*, 1941, Preprint No. 74
19 O. W. Ellis. *Amer. Soc. Met.*, 1943, Preprint No. 30.
20 *Commonwealth Engineer*, 1943, **30**, p. 183.
21 F. F. Vaughn, V. R. Farlow and E. R. Meyer. *Trans. Amer. Soc. Met.*, 1942, **30**, p. 516.

heating period, and in this case especially it is usual to aim at a case-depth equal to the theoretical depth of penetration of eddy currents in the steel in use.

Material Substitution.—Medium carbon non-alloy steels and high-tensile free-cutting steels when induction hardened will meet the same strength and hardness specifications as the usual nickel or nickel-chromium steels after carburising. However, when substituting plain carbon steels for low-alloy steels in this way, in some cases it may be advisable to increase the thickness slightly in places to give added strength. For example, when a spiral bevel gear, formerly made of 2% nickel-molybdenum carburising steel, was changed to high-tensile free-cutting steel, about $\frac{1}{4}$ in. was added to the back face of the gear.[22]

The Technique of Induction Hardening

Choice of Frequency.—In many cases the frequency is defined by the generator, especially if the latter is of the rotary type. This is a severe limitation, as it is extremely useful to be able to choose the frequency to suit the work.

For cylindrical specimens the optimum frequency may be obtained, by calculation or by reference to graphs, if the "index ratio" for the final result is known. (N. R. Stansel in discussion[17]). The index ratio represents the proportion of the total cross-sectional area of the bar which is to be hardened. The theoretical aspect of this ratio has been fairly fully worked out.[7]

For pieces of more complicated form there are other considerations. Large, fine-pitched gears can be hardened on the tips and meshing surfaces with 3,000 cycle current, whereas for coarse-pitch gears and for splines 10,000 cycles would be necessary in order that the hardened zone may follow the surface contour at all. 100,000 cycles would be required to provide a continuous case over the roots as well as the tips of the teeth. Where there are small changes in the surface, such as oil-holes in the bearing-surfaces of crankshafts, a low frequency, of the order of 2,500 cycles may be necessary to prevent local overheating.[23]

Power Required.[2]—The amount of energy required to transform 1 c.c. of steel at room temperature to the γ-modification at 800° C. is 4,600 joules—i.e., 1·1 kg. calories.

Therefore, if the depth of penetration of eddy currents is equal to the required depth of hardening, the specific power (i.e., power per unit area) required is—

$$P = 4{,}600\, p/t \text{ watts/sq. cm.}$$

where p = hardened depth required; t = time for which power is applied.

When the required case-depth is greater than the theoretical depth of penetration of eddy currents, and the heat is therefore transmitted to the required depth by conduction, the specific power depends on the temperature drop in the layer heated. The thermal conductivity of steel (0·8% carbon) in the range 600°–1,000° C. is 0·25 watts/° C./cm. Let T be the temperature drop in the heated layer—i.e., the temperature difference between the surface and that point in the steel which will just harden to the required extent; then in the steady state the flow of energy into the metal will be:

$$P = 0{\cdot}25\ T/p \text{ watts/sq. cm.},$$

and it is this expression which will determine the choice of power input and heating time.

In both the above expressions, heat losses, by radiation and by conduction into the partly hardened transition zone, are ignored. They are both small, especially in the first case, where heat is produced to the required depth, and the heating period is therefore of necessity short.

Timing.—Rather precise timing of the heating and quenching periods is necessary to give reproducible results, and an accuracy of $\frac{1}{10}$ sec. is often required. Either a series of cams or an electric timer may be used. It is sometimes necessary to control accurately the finish as well as the start of the quench, in order to allow of self-tempering. A short interval is often allowed between the end of the heating and the beginning of the quench, in order to allow some conduction to take place, thereby deepening the case, and making the temperature of the part to be hardened more uniform.

Quenching

Four methods of quenching have been employed. These are:—

1. *Self-quenching.*—This is only effective for very thin cases, such as are obtained with high frequency and high power input. A hardness of 750 D.H.N. has been obtained to a depth of only 0·007 in. by self-quenching, but required a frequency of 5 megacycles and a time of only 0·6 sec.[24]

2. *Spray-quenching.*—The quenchant, almost invariably water, is supplied in jets at the correct time, from either the heating coil, the concentrator if one is used, or some separate fixture. It is usually necessary to supply large quantities of water under pressure,[18] and the direction of the jets must be selected with some care.

For continuous hardening and for internal hardening, spray-quenching is used almost exclusively.

A special type of spray-quenching, and intermediate between that and self-quenching, is quenching with compressed air.[25] This method would appear capable of wider application in view of the high frequencies and powers now available.

3. *Dip-quenching.*—However, unless a great quantity of quenchant can be supplied very uniformly, a difficult matter if it has to be done from jets outside the heater coil, soft spots are liable to occur, and it is preferable to use dip-quenching when possible. In addition, there is less danger of water vapour leading to a break-down of the insulation between the turns of the coil. The principal difficulty with dip-quenching is the purely mechanical one of transferring the specimen to the quenchant in anything less than about 0·2 sec.

4. *Immersion Heating.*—In order to obtain the advantage of immediate and total contact with the quenchant with neither the difficulty of forcing the latter through the coil, nor of dropping the work-piece out of the coil, which may be almost impossible with assymetric specimens, both the piece and the coil may be immersed during the heating and the cooling.[8] In this case, during the heating period a layer of vapour is formed round the specimen, and helps to protect it from rapid heat loss.[5]

"Streaky Heating"

Any slight irregularities in the magnetic field due to the coil design lead to very much larger irregularities in the rate of heating. In the case of multi-turn coils, there will inevitably be a slight variation in the field,

22 F. W. Curtis. *Steel*, 1942, **110**, p. 73.

23 F. W. Curtis. *Machinery*, 1944, **64**, p. 119.
24 V. W. Sherman. *Heat Treating and Forging*, 1943, **29**, pp. 452 and 533.
25 A. Makhanek. *Etal*, 1938, p. 46.

and even if this is only of the order of 0·5%, when the steel reaches a temperature of 500°–600° C. there will be a noticeable difference in the brightness of parts immediately under a turn of the coil and those parts between two turns. This difference is destroyed as soon as the Curie point is reached.

The effect is probably due to the instability of the process of energy transfer from the coil to the work-piece.[2] Initially, there will be a very slight difference in the rate of heating at different points in the bar, proportional to the magnetic differences, and this will lead to a rise in resistance of the more strongly heated parts, with a corresponding rise in the efficiency of energy transfer at these parts, and therefore a further increase in the temperature differences. When the Curie point is reached, the parts above it are heated much less efficiently than those below it, and the case depth will become steadily more uniform. A high degree of uniformity of the magnetic field is therefore only necessary where an especially thin case is desired, and where this depth may be exceeded in one place before the surface in another has reached the temperature necessary for quench-hardening. In addition, there is a smoothing effect owing to conduction when the depth of case required is greater than the depth of penetration at the frequency used.

Temperature Measurement

In order to determine the temperature from which a part is quenched, a series of readings with an optical pyrometer is necessary.[18] A temperature-time relationship can be established by taking the time for a piece to be heated to a pre-selected temperature as shown by an optical pyrometer sighted on the specimen through a slot in the inductor block, and from this the temperature reached in any particular case can be established.

As the accuracy of an optical pyrometer is very dependent on the conditions of use, these must be standardised, and the instrument shielded from all extraneous light. It should be calibrated for the material in use, owing to the low emissivity of the usual bright machined surface, by comparing its reading on the surface of a piece of the same material, with the temperature shown by a thermo-couple immersed in a well of some molten alloy as near as possible to the part of the surface on which the optical pyrometer is focused.

Heating of Convex and Concave Surfaces. (E.G. Gears)

On convex surfaces the depth of magnetic flux penetration will be greater, and on concave ones less, than—

$$\frac{1}{2\pi}\sqrt{\frac{\rho}{2\mu f}}$$

Hence the eddy-current density will be less at the prominences than at the cavities of the work-piece, and the heating effect will vary in the same way. However, the higher the frequency and therefore the less the depth of penetration, the less this depth will be affected by the curvature of the surface. Hence, for most uniform heating, the frequency should be the highest available.

The higher concentration of energy in the cavities is partially compensated by the greater distance from the coil, and more especially by the greater conduction of heat into the interior of the specimen at places where the surface is concave.[2]

Efficiency

The " coupling " of a work-piece to its coil is defined as the ratio of cross-sectional area of the piece to that of the coil. The efficiency rises with this ratio, but provided that the specimen occupies at least 90% of the coil, a change in coupling ratio has only a small effect on efficiency of energy transfer when an external surface is being heated.[3, 8] With parts of complicated shape which cannot be made to even nearly fill the coil, some of the otherwise " waste-space " may be taken up by a concentrator, thereby considerably increasing the efficiency.

For highest overall efficiency, it is necessary to match the work-coil to its power supply, especially if the coil is part of a resonant circuit.

The technique of locally heating steel by induced electric currents is still in the experimental stage. Although the method is already proving of wide use, a considerable amount of work remains to be done, both to determine the range of application of the process, and to determine the best technique in individual cases. Enough has been done, however, to show that a new and extremely valuable way of treating steel to give a desired combination of properties is now available for general use.

In conclusion, the author would like to express his appreciation of the assistance received from the Library of the Iron and Steel Institute in the preparation of this brief summary of literature on the subject of the induction hardening of steel.

British Fluorspar Producers Association

The annual general meeting of the above Association was held on April 11, at Matlock. The chairman, Mr. Frederick Franks, welcomed the presence of Mr. A. G Bennett from the Fluorspar Control, Ministry of Supply, and representatives of Durham producers. Reviewing the work of the past year, mention was made of the close co-operation which existed between the Association and the Fluorspar Controller, Mr. W. T. Vizor-Harmer. Fixed prices and grades had been introduced for the first time, and these had been in operation for over six months with general approval. The home market had almost monopolised production, but a start had been made with export. During the year, serious attention had been given to acquiring a central plant in Derbyshire for processing fluorspar up to the higher grades. The proposal had been considered in conjunction with the Raw Materials Development Board, but unfortunately the scheme had not matured, and it would be necessary to make enquiries in other directions.

The chairman stressed the need for loyalty by all producers to support the Association. It was necessary to continue to improve qualities and attention must be given to research. Without this, the industry would lapse to its pre-war chaotic state, and instead of British fluorspar being exported, we should have imports of the mineral. Mr. A. G. Bennett, of the Fluorspar Control, said the Association deserved the fullest support, and he hoped they would consider the question of a Marketing Board. In the early stages of the Control they had had great anxieties, and there had been danger that steel works would go out of production for lack of fluorspar. This had been remedied, but at one time the margin of supplies had caused real anxiety.

The Yielding Phenomenon of Metals

Influence of Speed and Loading Conditions

Part V

By Georges Welter

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The yielding phenomenon of metals, of importance in applied mechanics as well as in metallurgy, is not yet sufficiently understood. Besides a theoretical consideration, the various factors which have a pronounced influence on the yielding of metals such as the kind of testing machine with its load-indicating device, as well as the rate of plastic deformation of the specimen, have been investigated. In order to obtain additional results about the loading conditions of the specimen, a new direct loading machine with a special recorder was designed, and the stress-strain diagrams of this machine were compared to those of the rigid straining machine. Furthermore, the transmission of the loads from the machine into the test specimen without harmful secondary effects was studied by means of three types of newly developed universal joints which allow loading the specimen axially.

In order to understand the whole stress-strain diagram, an automatic time chronograph was designed.

Furthermore, the characteristics of the two types of machine, the rigid straining machine and the direct loading machine, were compared to each other during the static loading tests, as well as during the dynamic tests with the machine in normal operation. During these tests an artificial yielding effect was obtained by a relative displacement of the loading faces of the machines. Stress-strain diagrams were recorded under different loading conditions; diagrams showing a most characteristic difference between these two types of machines were obtained.

By means of a special device based on sliding friction between three plates screwed together, the dynamic behaviour during yielding of metals in both types of testing machines was analysed and interesting diagrams were recorded. The rigidity of the straining machine could be gradually decreased by inserting elastically stressed elements between the grips and the frame of the machine. In five different steps the characteristics of the rigid straining machine were gradually made nearly equal to those of the direct loading machine.

Comparative tests with usual extensometers measuring in different places the relative movements of the grips and the loading faces of the machine gave valuable indications about the reliability of these instruments.

The upper and lower yield-points of mild steel were studied in function of the speed between about 400 lb. and 20,000 lb. per min. These tests show that the lower yield-point is much more affected by high deformation speed than the upper yield-point.

Time-controlled stress-strain diagrams show in all loading phases important variations of the loading speed in the rigid straining machine and the straining speed in the direct loading machine. The difference between the two types of machines becomes especially effective by comparing the stress-strain diagram of duralumin test specimens tested shortly after quenching and showing a very characteristic yielding effect.

In Fig. 62 and 63 are represented diagrams made under identical test conditions; diagram 62 was made with the electrical extensometer attached to the sliding device and having a magnification of 250 instead of 1,000.

F–(a) (2)—*Cord Extensometer.*—Diagram 63 was made with the roller and cord extensometers fixed directly to the sliding device. The results obtained with this set up, controlled by the time recorder and by tightening gradually the screws of the sliding device, are the same as those obtained with the electrical extensometer, Fig. 62.

F–(b) (1)—*Elastic Machine with sliding Device and Electrical Extensometer.*—If under the same testing conditions the machine is made highly elastic by means of the two helical springs inserted in parallel under the lower cross-piece of the machine and the lower grip of the specimen, the diagram obtained is as shown in Fig. 64. Instead of falling in numerous single steps, the load falls in this case from a maximum value of about 1,400 lb. to about 520 lb. in about 6 secs., so that at the beginning the drop of the load per sec. is much higher (about 250 lb. per sec.), compared to that shown in Fig. 61. Also the slope of the dropping phase B–C is about the same as that of Fig. 61. This means that these two characteristic values of the recording device are completely independent of the behaviour of the test specimen during yielding and are exclusively related to the recorder itself and the load-controlling device of the machine. The recorder cannot follow, even approximately, the movement between the grips. While it takes about 6 secs. (b–c) for the load to adjust itself to the lower value, it takes the recorder drum about 48 secs. to arrive at the end position of the elongation taking place instantaneously in the slipping device (that is about 0·2 in.). It must be said that in this case the admission valve of the machine was closed immediately after the yielding in point *B* had started in order to facilitate the readjustment of the recorder in a minimum of time. These results were obtained by an artificial yielding process in the slipping device.

In order to show that there does not exist any difference between the yielding and the sliding device and the phenomenon observed directly on the

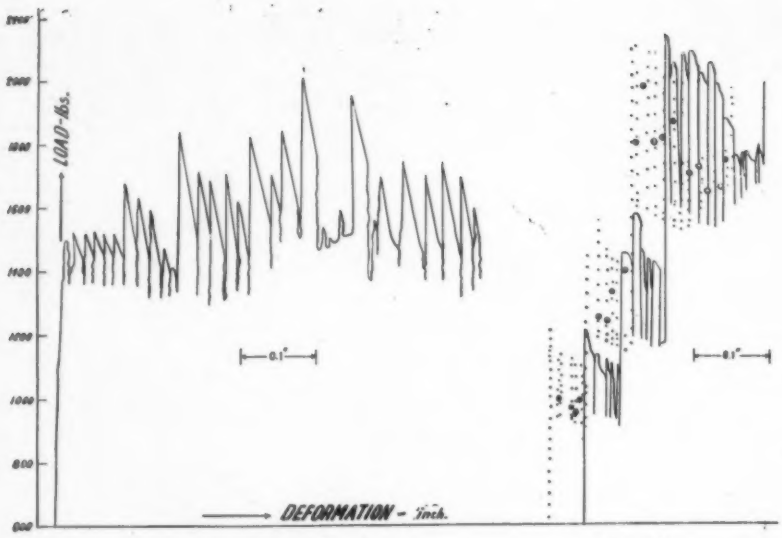


Fig. 62.

Fig. 63.

test specimen, the following test was made with a cylindrical specimen of mild steel about $2\frac{3}{4}$ in. long and about 0·22 in. in diameter. For this diameter, yielding took place at about the same loading range as that used with the sliding device. Under the same testing conditions, that is with the machine fitted with two helical springs in parallel, attached to the lower grip, and with the Peter's Templin extensometer fixed directly to the specimen, the diagram according to Fig. 65 with time record was obtained. The load increase in the elastic period was of about 400 lb. per min. Yielding started at about 1,700 lb. in *B* and the dropping of the load from *B* to *C* shows the same characteristics as that one of Fig. 62. Considering that the speed of rotation of the drum was about four times smaller as for Fig. 62, the dropping of the load is yet smaller than for that test. About $1\frac{1}{2}$ min. were necessary before the extensometer could adjust itself again to the total elongation of the test specimen in the yielding period, and this with the machine stopped immediately after initial yielding in *B* took place.

It can be seen by this experiment that under these conditions the electrical recorder is not at all able to give a true picture of what happens really in the specimen itself, fixed in the machine. This instrument is far too slow to follow and record these somewhat dynamic, extremely rapid effects of the test specimen. Besides that, the machine itself, as already shown, does not indicate the true yielding load for each moment of the yielding process.

F–(b) (2)—*Cord Extensometer.*—Also the usual cord recorder attached directly to the sliding device by fixing a pulley to the upper grip and another to the lower grip, does not give satisfactory results for this rapid test. According to Fig. 66, at a loading rate of 500 lb. per min. in phase A–B, for both tests sliding started at about 1,370 lb. in *B*. This extensometer, as distinctly shown, indicates right at the beginning of the yielding process an elongation B–C, marked by a nearly horizontal line. This takes place in less than 1 sec. (time marks b–c). Due to this sudden elongation the load of the straining machine drops down during this process relatively slowly, so that point *C* is only 50 lb. to 60 lb. lower than *B*. If the load, however, fell as quickly as the sliding itself takes place, there ought to be a straight line recorded between *B* and *D*, the maximum and minimum loads (500 lb. for diagram No. 1, 450 lb. for diagram No. 2) attained respectively after yielding. In this case, however, the deformation D–C is right at the beginning recorded with a small loss of load in about less than 1 sec. and after that initial accelerated drop, the load continues to fall down from *C* to *D* in about 5 to 6 secs. (time marks c–d–e–f–g). Even if this extensometer reacted much faster to the elongation during B–C it would still have the further disadvantage that it does not indicate the total sliding length of the device which is in reality 0·21 in. This means that the distance B–C ought to be more than the double of that one recorded. Consequently this recorder is also completely inadequate for this kind of very fast but small movements of the grips under load.

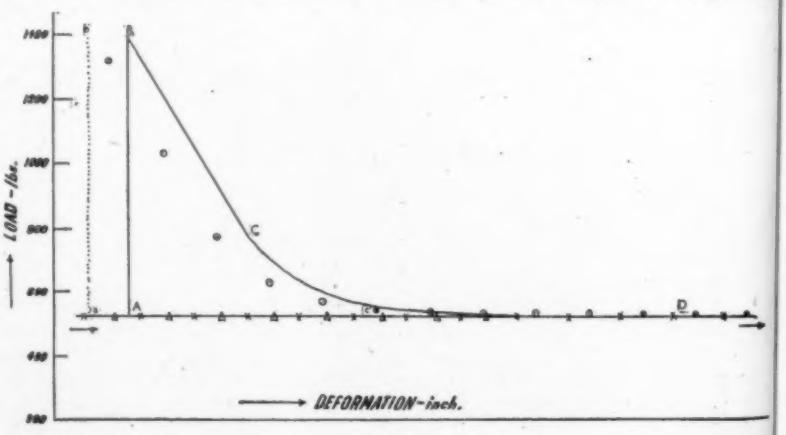


Fig. 64.

G–RIGID STRAINING MACHINE CAN BE CHANGED INTO DIRECT LOADING MACHINE (wormgear device and cord extensometer between grips of machine in operation)

In the preceding paragraph *E* it was shown that variations of the stiffness of the rigid straining machine in fairly wide limits are possible either by elastic deformation of a bar and beams or by helical springs in parallel adjusted under the lower cross-piece of the machine. In order to prove, however, by direct records that the theoretical considerations exposed in A–(b)–(2) and A–(c)–(1) concerning the different degrees of rigidity of the machine and their influence on the important part of the load dropping in the stress-strain diagram, correspond

really to the true behaviour of the machine in testing practice, the following series of tests for different variations of the stiffness of the rigid machine up to a maximum change, were made. As already shown, the sliding device placed between the grips of the machine as well as the recorder attached to the loading points of the

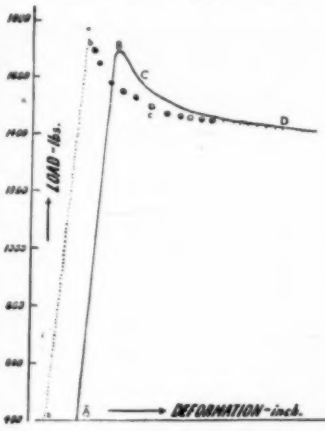


Fig. 65.

machine, gives the most reliable results, approaching very near the real behaviour of test specimens. The series of test was therefore arranged by placing the worm-gear device as well as the cord extensometer between the upper and lower grips of the rigid straining machine, as shown in Fig. 67. The worm-gear device was chosen and not the sliding device, because it was preferable to obtain more or less reliable semi-dynamical records. The diagrams of the sliding device, due to the inertia of the different heavy parts of the machine frame as well as those of the loading indicators, do not correspond, as already known, to the real sudden changes in the load equilibrium of the machine and the test specimen. As the results with this rigid straining machine are already described in D–(a)–(1), Fig. 44, there will be dealt with only results of the tests made with different degrees of stiffness of the standard machine.

(a) Two helical springs in parallel between lower cross-piece and the grips of the machine

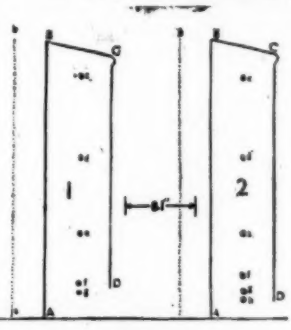


Fig. 66.

Fig. 68 represents two diagrams recorded with a Baldwin machine under two different loading speeds, the machine being made highly elastic by inserting two helical springs in parallel between its lower cross-head and its grips. For the first diagram No. 1, Fig. 68, the loading speed was, as can easily be seen by the dotted time record, of about 800 lb. per min., and the maximum load reached was of about 2,120 lb. The slope of the line A–B cannot in this case be taken into consideration and does not interfere with the results, as it was influenced during the loading period by a small

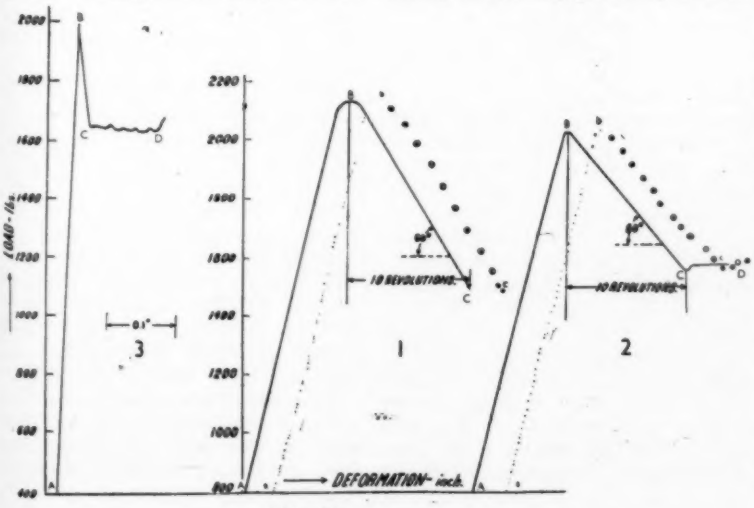


Fig. 64.

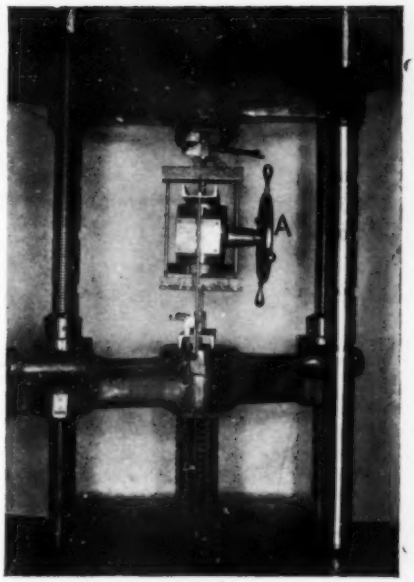


Fig. 67.

vertical relative displacement of the cord extensometer itself attached to the specimen with regard to the recorder drum. To obtain the characteristic drop of the load, the hand-wheel *A* of the worm-gear device placed between the grips, according to Fig. 67, was, at the load *B*, given about 10 revs. in 10 to 11 secs. This represents a total displacement between the grips of about 0·21 in., while the machine was in operation. This increase of the distance between the grips provokes a drop of the load of about 640 lb. to about 1,480 lb. in *C*. According to the time record this drop took place in about 10 to 11 secs., that is in about the same time as that of the operation period of the hand-wheel (11 secs.). This proves that the recording device and the machine could follow this fairly slow drop of the load with the same speed as it really took place. It can also be seen, that the load does not drop nearly vertically as in the rigid machine (compare diagram Fig. 44; displacement of 0·021 in. only made by 1 rev. of the hand-wheel), but the load falls with a slope of about 60° from *B* to *C*, Fig. 68. This is due in the first instance to the insertion of the two helical springs in parallel in the machine, as represented in Fig. 67. From the point *C*, the load could be easily kept constant during the operation of the machine at the lower yield point of the diagram by turning the hand-wheel with a slower speed than that used during the period B–C.

Another diagram was obtained under similar conditions, only with a higher initial loading speed A–B of about 1,300 lb. per min., as represented in No. 2, Fig. 68. The maximum load attained in *B* is of 2,030 lb., and the slope of the drop B–C is somewhat smaller (50°), compared to diagram No. 1. This verifies the theoretical consideration that the loading speed has a certain influence on the slope of the drop of the load. This slope becomes flatter, the higher the rate of loading is increased [see paragraph A–(c)–1)]. The horizontal part C–D of this diagram is obtained at a load of about 1,580 lb. This load is kept nearly constant between *C* and *D* by turning the hand-wheel three times slower than in the dropping period B–C.

The principal result of these tests is the fact that, compared to the rigid machine (see diagram No. 3 or Fig. 44), the drop of the load B–C is not quite as steep but, with the variation of the rigidity towards a more elastic machine, this drop becomes flatter, so that for a slope of nearly 80° to 90° for the machine with two helical springs in parallel, it becomes about 50° to 60°.

(b) One helical spring between the lower cross-piece of the machine

The series of tests made with a yet softer machine inserting only one helical spring (instead of two) between the cross-piece and the grip of the machine, confirms already quite clearly the theory exposed in A–(b)–(2), that the drop of the load in the stress-strain diagram is a direct function of the rigidity of the straining machine. Fig. 69 shows that a machine with one helical spring only, being twice as springy as in the preceding tests, the drop of the load is consequently much flatter. For the same displacement of 0·21 in. between the grips (10 revs. of the hand-wheel) and with an initial loading speed of about 1,000 lb. per min. (22 secs. for 200 lb.) the load falls during 9 secs. from *B* at about 2,000 lb. to *C* at 1,660 lb. (Diagram No. 1). It is quite clear that the drop of the load is, for the machine with this grade of softness and a low loading rate, quite flat (only about 35°), so that under identical conditions the drop is only 340 lb., compared to about 640 lb., Fig. 68. To keep the load constant between *C* and *D* a lower speed (2½ times slower) of the hand-wheel was needed.

The influence of the loading speed in this series of tests is even more clearly visible in diagrams No. 2 and 3 recorded with a loading rate of about 1,700 lb. per min. and 2,000 lb. per min., respectively. For these higher rates, the drop of the load in B–C is already much flatter, showing a slope of about 15° to 18°, compared to diagram No. 1 with 35°; consequently the drop of the load in B–C is also smaller, and is only about 120 lb. to 140 lb.

By a yet higher loading speed of about 3,000 lb. per min. (4 secs. per 200 lb.) and an identical number of revs. of the hand-wheel (10 revs.) in a minimum of time (about 8 secs.) the load between *B* and *C* did not drop at all. It could easily be maintained at about the same load of 2,040 lb. during a certain time (4 secs.) going up to an even higher load of 2,100 lb. in *C*, Fig. 69, No. 4. This proves clearly that the loading rate has also a marked influence on the slope of the drop of the load in ordinary straining machines having the same degree of springiness.

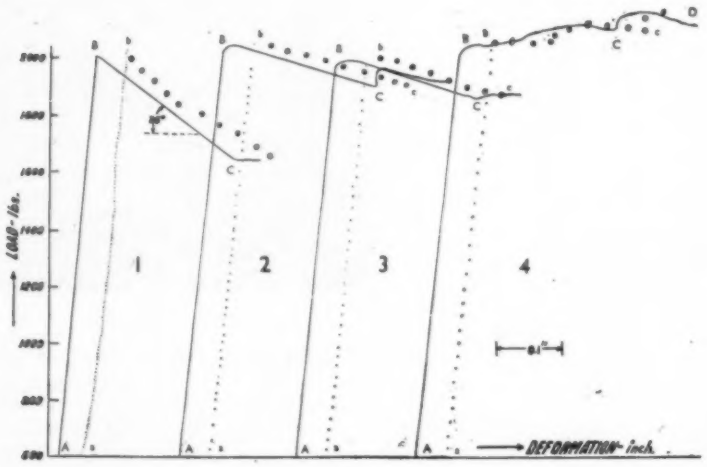


Fig. 69.

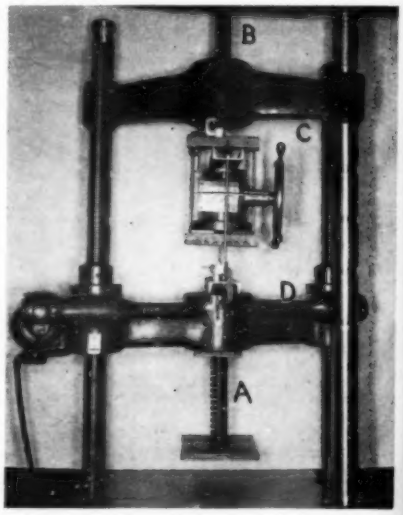


Fig. 70.

c) Two helical springs in series (one at each end between the cross-pieces and the grips of the machine)

To go still one step further in the variation of the rigidity of the straining machine, another adjustment giving a maximum of softness of the machine was made. As represented in Fig. 70, helical springs *A* and *B* were fixed at each side of the grips, acting against the cross-pieces of the machine *C* and *D* and increasing in this way appreciably the springiness of this machine.

In Fig. 71 is represented a diagram recorded with this set up under a loading speed of about 1,000 lb. per min. in the phase A–B. By the usual 10 revs. of the hand-wheel, in about 10 secs., the load did not, as in the preceding cases, fall from a higher to a lower value. Despite the increase of the distance between the grips of 0·21 in. in 10 secs. the load *B* of 1,660 lb. remained about the same during this whole period B–C; no drop of the load could be recorded.

This series of systematic tests on the springiness of the testing machines prove experimentally, not only what has been stated in paragraph *A* of this

work, that the rigidity of the machine is of prime influence on the shape of the stress-strain diagram, but that even an ordinary rigid machine of the standard type can be easily transformed in its characteristics so that, instead of a load decrease in the yielding phase, by gradually increasing the softness of the machine, a yielding diagram very similar to that of the direct loading machine can be recorded. Two helical springs adjusted between the grips of the specimen and the cross-pieces of the machine are sufficient to produce this profound change of the loading and straining characteristics of the rigid machine.

It is quite obvious that these profound changes of the rigid straining machine by inserting helical or other springs between the frame and the grips, are only possible in relatively low loading ranges of the usual machines. For much higher loads the desired characteristics can be obtained only by other kinds of spring. For instance powerful pneumatical or hydro-pneumatical devices can transmit much higher loads to the test specimen in very elastic machines.

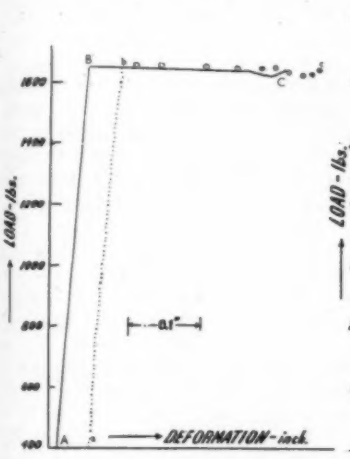


Fig. 71.

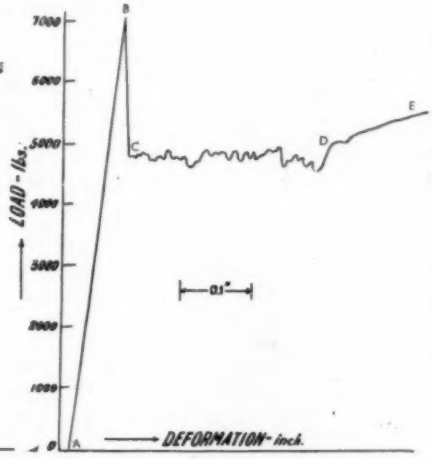


Fig. 72.

present some interest. For this purpose a mild steel bar of 0·4 in. diameter was chosen. To show clearly the effect of the upper and lower yield points, a specimen with a somewhat exaggerated effective length of 8 in. was stressed in the rigid straining machine. The diagram obtained with the cord extensometer, the pulleys being placed as usual between the loading tables, is represented in Fig. 72. This is a rather characteristic stress-strain diagram A–B–C–D–E of mild steel having a very pronounced drop of the load B–C between the upper and lower yield points at 7,000 lb. and 5,000 lb., respectively. Furthermore, the excessively long yielding period C–D at the lower load is due to the somewhat exaggerated length of the test specimen. The drop of the load is about 28% to a lower value of 5,000 lb. with variations of ±40 lb. between C–D, and the total yielding elongation of this specimen was of the order of 0·3 in., representing very characteristic phases in this diagram. From point *D* the load again started to increase regularly with the straining of the specimen.

If with this material a series of time-controlled stress-strain tests are made under widely variable loading speeds, that is between a minimum value of about 200 lb. per min. and a maximum value of about 20,000 lb. per min., then the influence of the speed of deformation on the yielding of the material becomes quite clear. In the following table are shown the results obtained at the different loading speeds for the upper and the lower yielding limits in lb. per sq. in. measured on specimens of 0·22 in. diameter and 3 in. length.

TABLE II.

Loading Speed lbs./min.	Upper yield point lbs./sq. in.	Lower yield point lbs./sq. in.	Time of total yielding at lower yield point sec.
200	45,200	37,000	650
800	46,300	38,400	375
2400	47,000	40,000	66
6000	47,200	42,200	28
20000	—	43,400	12

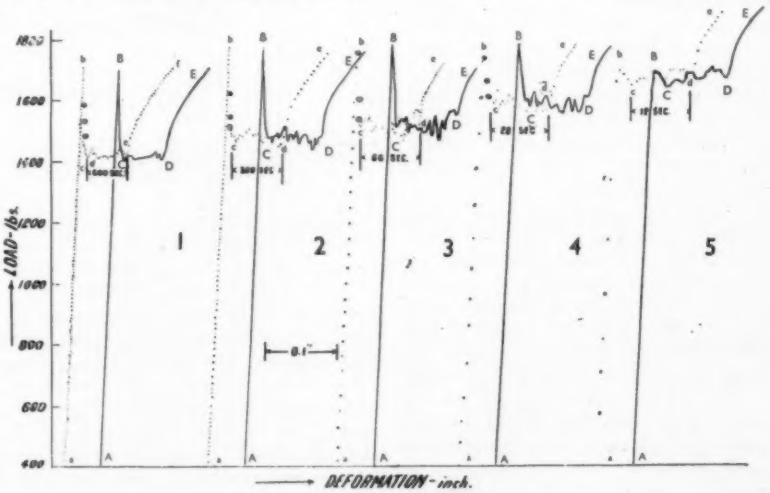


Fig. 73.

H—INFLUENCE OF LOADING SPEED ON UPPER AND LOWER YIELD POINTS OF MILD STEEL

After having studied the mechanical part of the question about yielding accompanied by a drop of the applied load in the specimen and this also from the point of view of loading speed, the stress-strain diagram obtained with test specimens of mild steel showing an upper and lower yield point may

It can be seen by these results that the difference between the upper and lower limit of yielding is much greater for low speeds (a difference of about 7,800 lb. per sq. in. for a speed of 200 lb. per min.) showing a difference

of only 5,000 lb. per sq. in. for a loading speed 30 times greater.

Furthermore, the upper yield point does not grow with increasing speeds of loading as fast as the lower one; between 200 lb. and 600 lb. per min. the upper yield point increased in the first case only by 2,000 lb., while the increase of the lower yield point was of more than double this value (4,200 lb. per sq. in.). For a loading speed of 20,000 lb. per min. the lower yield point is about 16% higher than that measured at the lower speed.

The stress-strain diagrams, each with its respective time record, representing the elastic phase A–B as well as the complete yielding with the upper yield point *B*, the drop of the load B–C, the yielding at the lower load from *C* to *D* and the beginning of the load increase D–E, are represented in diagrams Nos. 1 to 5, Fig. 73. These diagrams do not require any special comment; the principal phases are clearly distinguished and the dotted lines of the time recorded permit to verify the loading and straining speed in the different phases of the tests. It can be seen for instance, that with an increasing loading speed the space between the single time points in the dotted lines becomes greater (a–b). On the other hand, however, in the phase B–C the time necessary for the dropping of the load is independent of the loading speed and is for all diagrams nearly the same. The drop of the load from the upper to the lower limit takes place in about 3 to 4 secs., a speed which was also observed during the preceding series of tests made with the artificial yielding device. This fact proves again that the dropping rate of the load during the first yielding period has nothing to do with any mechanical quality of the test specimen but is exclusively influenced by the loading and recording mechanism of the rigid straining machine employed. The straining speed in the period C–D for diagrams 1 to 3 was much greater than that corresponding to the loading speed in the elastic phase A–B this was done because under normal conditions the yielding speed in this period C–D is so slow that points of the dotted lines become so close together that they form a continuous line in which the single points are completely indistinguishable. To avoid this, beginning from point *C*, either the straining speed of the machine can be increased, or the autographic chronometer can be regulated in such a way that the points are marked only every 15 or 30 secs. for instance, instead of each second as for phase A–B–C. This last way was chosen for the recording of diagrams No. 1 and 2. Part a–b–c of the time diagram No. 1 is recorded with 60 points per min., while in the part from *d* to *e* and *f*, the distance between each point represents 30 secs. For diagram No. 2 the time diagram a–b–c was recorded with 60 points per min., while the yielding period c–d–e was recorded with 15 secs. between each point. For diagram No. 3 during the whole test the points were recorded with the interval of 1 sec. without changing the position of the admission valve of the machine during the whole test. It is interesting to note that in spite of the high loading speed (4 secs. per 200 lb. for No. 3) in the elastic phase A–B, the drop of the load takes place again in about 3 secs., and in the real yielding period C–D the yielding speed is fairly slow. About 66 secs. were necessary before the load started to increase again at the end of this period in *D*. From *D* to *E* the load increase at the very beginning, is as noticeable in the other time diagrams, somewhat greater than shortly afterwards where the load increase slows down with the increase of plastic deformations. For a loading rate of 6,000 lb. per min. the yielding period lasted only 28 secs., as shown in diagram No. 4 and for a speed of 20,000 lb. per min., only 12 secs. were necessary to record the part C–D of the diagram No. 5. For the time record of this diagram the intervals between two time points had, contrarily to diagrams Nos. 1 and 2, to be decreased in order to have sufficient time marks recorded. In this case 10 points were marked in 6 secs. Furthermore, an upper yield limit was not recorded under these high speeds. The yielding speeds in function of the loading speeds are represented in Table II.

A diagram with yet higher loading speeds, that is of about 32,000 lb. per min., was recorded, but here too an upper limit was not visible; furthermore no appreciable variation of the load at a lower yielding period took place. By this test made with high straining speed it became evident that the recorder could not follow the yielding in all its phases since it takes place in about only 4·5 secs. It is indicated by an horizontal line.

To be continued.

Processing of Beryllium

By D. M. Liddell

THE modern processes described are largely based on bringing beryllium into solution as an alkaline fluoberyllate. Alternately the beryllium is dissolved as beryllium sulphate or chloride. All such processes spring from the fact that alkaline fluorberyllates are soluble in water, while beryllium fluoride is not. In the Perosa process for the recovery of the metal, beryl is heated, then crushed and ground, so it all passes 100-mesh screen. It is then mixed with acid sodium fluoride in atomic proportion of 1 : 4, and the mixture is briquetted. The beryllium is converted to sodium fluoberyllate when the briquettes are sintered at 650° to 800° C. The sintered briquettes are then crushed and ground and leached with hot water. Sodium hydroxide is added, making the mixture exactly neutral and purifying it from iron, manganese and alumina; and then potassium permanganate is added. The iron-manganese-alumina precipitate is filtered off, and an excess of sodium hydroxide is added. Beryllium hydroxide is precipitated, filtered off, washed and dried. After drying, the material is ground in a paint mill with acid ammonium fluoride, which converts the hydroxide to ammonium-beryllium fluoride. This is then briquetted and heated sufficiently to drive off the ammonium fluoride, leaving pure beryllium fluoride behind, which is then reduced with magnesium or a magnesium alloy in the presence of some of the metal desired for a master alloy. In this process, as in others, the high cost of fluorine necessitates its recovery out of the solution from which the beryllium hydroxide is precipitated, and out of the slag of the final reduction as well.

From a paper read before the American Institute of Mining and Metallurgical Engineers, Cleveland, Ohio. October, 1944.

SOME months ago we published an article, "The Instrument as an Analytical Tool," which discussed the implications raised by the increasing use of instrumental methods in the field of analytical chemistry. A further contribution to this theme is to be found in the recent Inaugural Address, by R. C. Chirnside, to the Physical Methods Group of the Society of Public Analysts and Other Analytical Chemists, which has just been published, and which is reviewed at length below. In his address, after discussing the many physical methods now available to the analyst, the speaker goes on to consider how the position of the analyst himself is affected. Like our own contributor, he feels that the general analyst will require a much broader education in the future, and that analysis in its fullest sense must largely be a matter for experts. In both papers, there is implicit a radical change in the attitude towards the analyst, and the Inaugural Address merely puts in other words what we have maintained frequently in these columns—"Another possible outcome is that the status of the analyst may grow again, and there is room for growth: for too long he has been the poor relation of the chemical fraternity." Mr. Chirnside's address contains much of interest for the analyst. But it is rather to the non-analyst, and to the chemist who tends to regard the analyst as most people regard a dustbin—necessary but rather unlovely—it is to such that we recommend with greatest vigour a close study of the address.

Qualitative Inorganic Microanalysis Without Hydrogen Sulphide—Part II.

By R. Belcher and F. Burton

This portion of the article gives, in schematic form, details of the methods which were outlined in Part I.

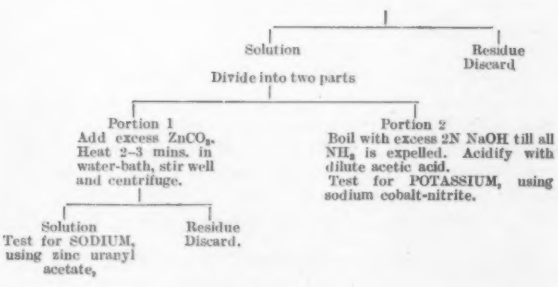
The first part of this paper discussed the advantages and disadvantages, in general terms, of analysis without sulphuretted hydrogen. The principles underlying the present scheme were described.

In the following description of the scheme it is assumed that the reader is familiar with the general technique of qualitative microanalysis. Those who are not should consult the paper by C. C. Miller[9] or the text book by C. L. Wilson[10] dealing with this subject.

Group I

I. *Test for Ammonium.*—Apply Nessler test to a fragment of the original substance or to a drop, if in solution, using the "hanging drop" cell.[10]

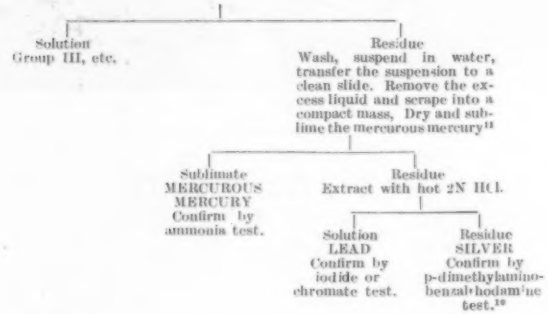
II.—*Tests for Potassium and Sodium.*—Boil a portion of the original substance with ammonium phosphate solution. Cool and centrifuge.


Solution
Residue
Discard
Divide into two parts
Portion 1
Add excess $ZnCO_3$. Heat 2–3 mins. in water-bath, stir well and centrifuge.
Portion 2
Boil with excess 2N NaOH till all NH_3 is expelled. Acidify with dilute acetic acid.
Test for POTASSIUM, using sodium cobalt-nitrite.
Solution
Test for SODIUM, using zinc uranyl acetate,
Residue
Discard.

9 C. C. Miller. *Metallurgia*. 1944, **31**, 39.
10 "An Introduction to Microchemical Methods," by Cecil L. Wilson. Methuen, 1938.

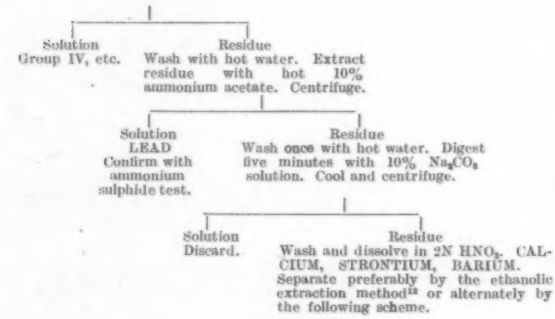
Group II

Treat two or three drops of the solution of the substance with 11N HCl in a cone. Centrifuge.

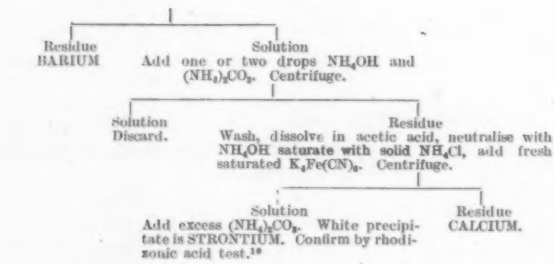


Group III

Evaporate the solution from II to the original bulk, if necessary, and add an equal volume of saturated Na_2SO_4 solution. Add an amount of ethanol equivalent to twice the bulk of the solution. Rub the sides of the cone with a glass thread to expedite precipitation. Allow to stand 2 or 3 mins. Centrifuge.

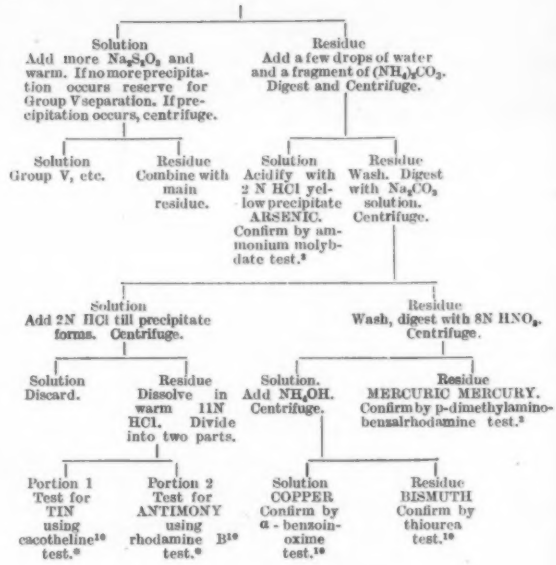

Solution
Group IV, etc.
Residue
Wash with hot water. Extract residue with hot 10% ammonium acetate. Centrifuge.
Solution
LEAD
Confirm with ammonium sulphide test.
Residue
Wash once with hot water. Digest five minutes with 10% Na_2CO_3 solution. Cool and centrifuge.
Solution
Discard.
Residue
Wash and dissolve in 2N HNO_3. CALCIUM, STRONTIUM, BARIUM. Separate preferably by the ethanolic extraction method[12] or alternately by the following scheme.

Dissolve the washed carbonates in acetic acid. Warm, add excess $K_2Cr_2O_7$. Centrifuge.



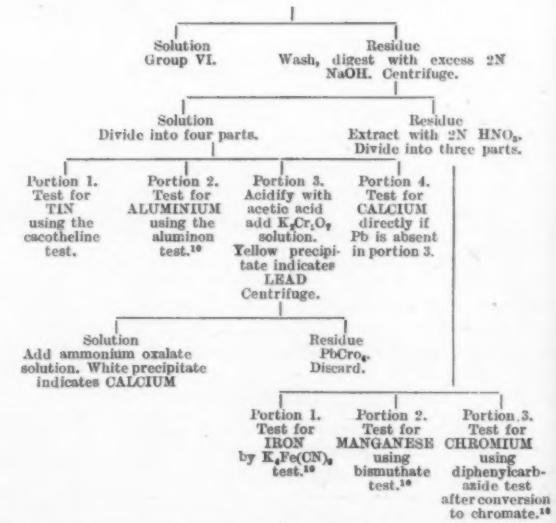
Group IV

Evaporate the solution from III to expel ethanol. Cool, add NH_4OH carefully until ammoniacal. Warm and add 2N HCl until any precipitate formed just dissolves or until the solution is slightly acid. Add 10% $Na_2S_2O_3$ solution and warm two to three minutes. (If only a white precipitate of sulphur forms, Group IV metals are absent, therefore continue with the next group.) Centrifuge.



Group V

Evaporate the solution from IV to the original bulk. Add two drops of aqua regia and digest. Centrifuge and separate the sulphur. Test a part of the solution for phosphates and, if present, separate as follows. Make the solution about 5N to HCl and add six drops of zirconium nitrate solution. Stir and warm. Centrifuge and add another drop of reagent to ensure precipitation is complete. Discard the residue of zirconium phosphate. Add a few crystals of NH_4Cl and continue the separation as below. If phosphates are absent, proceed with the normal separation. Add excess NH_4OH and three or four drops of $(NH_4)_2CO_3$. Warm and centrifuge.

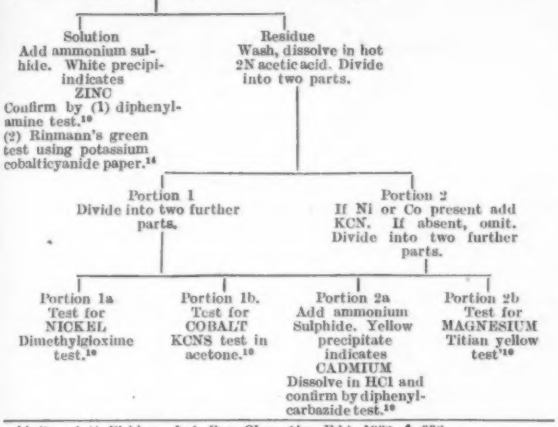

Solution
Group VI.
Residue
Wash, digest with excess 2N NaOH. Centrifuge.
Solution
Divide into four parts.
Residue
Extract with 2N HNO_3. Divide into three parts.
Portion 1.
Test for TIN using the cascotheline test.
Portion 2.
Test for ALUMINIUM using the aluminon test.[10]
Portion 3.
Acidify with acetic acid add $K_2Cr_2O_7$ solution. Yellow precipitate indicates LEAD Centrifuge.
Portion 4.
Test for CALCIUM directly if Pb is absent in portion 3.
Solution
Add ammonium oxalate solution. White precipitate indicates CALCIUM
Residue
$PbCrO_4$.
Discard.
Portion 1.
Test for IRON by $K_4Fe(CN)_6$ test.[10]
Portion 2.
Test for MANGANESE using bismuthate test.[10]
Portion 3.
Test for CHROMIUM using diphenylcarbazide test after conversion to chromate.[10]

11 Schoorl; Emich-Schneider. *Microchemical Laboratory Manual.* John Wiley and Son, Inc., N.Y.
12 Belcher and Burton. *Metallurgia*, 1944, **31**, 42.

* It will be found convenient to carry out these tests using the "spoon."[13]
13 Belcher. *Ibid*, 1944, Sept., 280.

Group VI

To the solution from V add excess 2N NaOH and boil until all NH_3 is expelled. Centrifuge.


Solution
Add ammonium sulphide. White precipitate indicates ZINC
Confirm by (1) diphenylamine test.[10]
(2) Rinmann's green test using potassium cobalticyanide paper.[14]
Residue
Wash, dissolve in hot 2N acetic acid. Divide into two parts.
Portion 1
Divide into two further parts.
Portion 2
If Ni or Co present add KCN. If absent, omit. Divide into two further parts.
Portion 1a
Test for NICKEL
Dimethylglioxime test.[10]
Portion 1b.
Test for COBALT
KCNS test in acetone.[10]
Portion 2a
Add ammonium Sulphide. Yellow precipitate indicates CADMIUM
Dissolve in HCl and confirm by diphenylcarbazide test.[10]
Portion 2b
Test for MAGNESIUM
Titian yellow test'[10]

14 Benedett-Pichler. *Ind. Eng. Chem.* (An. Ed.), 1932, **4**, 336.

The Determination of Zinc

ZINC-8-HYDROXYQUINOLATE shows a brilliant fluorescence, and when small amounts of zinc are precipitated by 8-hydroxyquinoline in the presence of gum arabic, it is possible to obtain sufficiently stable and reproducible colloidal suspensions of the precipitate to enable these to be used for the determination of zinc by measurement of the fluorescence-turbity in a fluorescence meter*.

The amount of fluorescence is read against a calibration curve, the instrument being reset when necessary against a standard dichlorofluorescein solution. Amounts of zinc ranging from 0·05 to 0·6 mgm. may be satisfactorily determined by this method, with an accuracy of ±0·02 mgm. The determination is carried out in an acetic acid-acetate buffer, at pH 5·9. Temperature should be controlled within ±2°, otherwise serious errors may arise. While the method is extremely rapid and simple, it is interfered with by other ions which are precipitated by 8-hydroxyquinoline at the same pH.

* L. L. Merritt, *Ind. Eng. Chem., Anal. Ed.*, 1944, **16**, 758.

Physics and the Analyst

THE inauguration of a Physical Methods Group of the Society of Public Analysts and Other Analytical Chemists followed very closely on the formation of the Microchemistry Group. Since, in many of their interests, the two Groups must necessarily encroach on common ground, the Inaugural Address will undoubtedly be of considerable interest to microchemists. In this address, R. C. Chirnside[1] reviews briefly a number of the newer methods which are now available to the analyst under the general heading of physical methods.

Recalling briefly the days when gravimetric analysis was the final court of appeal, and recognition was only given grudgingly to volumetric analysis, the speaker goes on to point out that it is some considerable time since physical weapons were first applied to analysis. (A number of these techniques have been discussed at various times in these columns, and references to appropriate articles in METALLURGIA will be included for the convenience of the reader.) Some of the earliest instances were in the use of such instruments as the optical microscope,[2] the refractometer, the polarimeter and the calorimeter. The list of modern additions is formidable in comparison with this. The speaker lists the following as being probably an incomplete catalogue : the spectrograph ; X-ray and electron diffraction, and the electron microscope ; the polarograph[3] with its subsidiary, amperometric titrations[4]; electrolytic[5] and electrographic analysis[6]; chromatography ; thermoanalytical methods ; the mass spectrograph[7]; physical methods of gas analysis ; electrometric methods ; absorptiometric and fluorescence measurements ; molecular and fractional distillation ; and the use of the ultra-centrifuge.

Mr. Chirnside first indicates the various regions in which the electromagnetic spectrum had proved of use to the analyst[8]. Firstly, the emission spectrum is probably the oldest and most firmly based analytical aid in this field*. For rapid control in metallurgical work, qualitative and quantitative methods have been devised both for the ferrous and non-ferrous industries. However, going from a specifically metallurgical use to a general inorganic viewpoint, the instrument is, of course, applicable to the rapid qualitative analysis of metallic constituents†, most particularly as a basis for planning the quantitative analysis. This, the speaker suggests, is probably the instrument's most important function in the hands of the analyst. Again, by inspection of the photographic plates it may often be possible to carry out a rough quantitative estimate of the constituents. Thirdly, precipitates, and, indeed, materials in general may be examined for the presence of inorganic impurities. Finally, the value of the spectrograph is great when only a small amount of material is available for analysis. The assistance of the instrument in two directions is particularly to be stressed : firstly to simplify the qualitative analysis leading to quantitative measurements, often cutting down time by almost half, since, in some cases, classical methods of qualitative analysis may involve almost as lengthy and difficult procedures as the quantitative ; secondly, the spectrograph reduces the personal error, in that it indicates the presence of elements whether these have previously been suspected or not.

Absorption spectrography, the companion to emission work, is in general concerned with a different field of analysis. Its value is largely derived from the variations in structure of organic molecules, and hence the method

1 R. C. Chirnside, *Analyst*, 1945, **70**, 110.
2 C. L. Wilson, *Metallurgia*, 1945, **31**, 213.
3 J. T. Stock, *Ibid.*, 1944, **29**, 155, **31**, 102. *Ibid.*, 1944, **30**, 220.
4 J. T. Stock, *Ibid.*, 1944, **30**, 221. J. T. Stock and M. A. Fill, *Ibid.*, 277.
5 H. J. S. Sand, *Ibid.*, 1944, **30**, 107. J. G. Fife, *Ibid.*, 167.
6 D. L. Masters, *Ibid.*, 1943 **29**, 101. *Ibid.*, 1944, **29**, 158.
7 *Ibid.*, 158.

8 *Ibid.*, 1945, **31**, 151. D. M. Gans, *J. Chem. Ed.*, 1944, **21**, 421.

* The use of the instrument dates from the middle nineteenth century, and is inextricably bound with the discovery of an appreciable number of the elements.

† It should be borne in mind that emission spectrography is also applicable in certain cases to a small number of non-metallic constituents.

is concerned chiefly with the analysis of complex organic mixtures. Both the infra-red and ultra-violet regions have been widely employed, though for plant control of synthetics such as rubber, the infra-red field has probably been most extensively developed. Formerly used as a qualitative guide only, recent work has provided quantitative indications of the composition of mixtures containing a number of fairly similar organic compounds such as one frequently meets in the petroleum industry. The time saved by such a method, when compared with the time necessary for the analysis of such a complex mixture by the older methods, constitutes a marked advantage of the method.

Chromatographic analysis, again particularly for complex organic mixtures such as those encountered when dealing with natural products, is soundly established as an analytical procedure. This method of separation may often be combined to fuller advantage with other physical methods of analysis.

The analysis of gases by ordinary microchemical methods may frequently handle samples as small as 0·1 ml., in capillary burettes with solid absorbents*. In the electrical industry much smaller quantities of gases, of the order of 0·001 ml., such as the gases contained in metals to be used in vacuum apparatus, may often require analysis. Physical methods are able to handle this problem, the gases being manipulated and measured at very low pressures. Specimen analyses of quantities of the order of 0·01 ml. of a mixture containing carbon dioxide, hydrogen, carbon monoxide and nitrogen compare very favourably with a macroanalysis, by classical methods, of 50 mls. of the same gas mixture This technique may also, of course, be applied to such problems as the determination of carbon in metals, by combustion of the element to carbon dioxide.

The mass spectrograph is an instrument which is usually associated with fundamental problems of atomic structure, but recently it has been developed as a molecule-sorter for complex organic mixtures. Although still in its preliminary stages, the application of the instrument to such mixtures as a series of paraffins has been successful.

X-ray diffraction methods of analysis are of first importance, particularly in conjunction with other instrumental methods ; while electron diffraction investigation gives information about surface films which is complementary to the information regarding the bulk of the material obtained from the X-ray method. The electron microscope has extended by more than fifty times the magnifications formerly available with the optical microscope, and hence has made feasible the examination of structural detail which was previously purely a matter of conjecture.

The polarograph, although possibly rather overworked by some analysts, is valuable for determining traces of impurities in pure metals, dealing as it does with quantities which come definitely into the category " microchemical."

Lastly, absorptiometric methods, which have developed largely from the older " colorimetric " methods, primarily through instrumental improvement, are making themselves a well-defined field in the rapid schematic quantitative analysis of such routine specimens as metallurgical samples[9]. The earlier colorimetric methods were frequently confined to trace elements, because of the sensitivity of reagents. The instrument has overcome this difficulty, and has thus extended enormously the field to which such analyses can be applied. There is consequently more tendency to avoid time-consuming separations, by devising methods or reagents which are applicable to mixtures directly. While the greatest use of absorptiometric methods is probably in routine analysis, they may be widely applied to work of a more general or miscellaneous type.

Mr. Chirnside concludes his address with a consideration of the effect of all this development of resources on the position of the analyst. Like a previous writer in these columns[10] he realises that although the analyst is going to be profoundly affected, it is extremely difficult to forecast the precise manner in which his status is to be altered. Ever-increasing use will be made of instruments, but it must be remembered that analysis is important primarily because of its results, rather than because of its method. In other words, the new tools must be employed with discrimination if full advantage is to be reaped.

Finally, it is to be hoped that with the renaissance in analytical methods will come a corresponding reassessment of the importance of the analyst to science. Routine analysis, which is a necessary part of chemistry, should tend to become a branch which might be referred to as " testing " (or testing should cease to be referred to as analysis !) and the analyst, able to turn his hand more completely to the more exacting work which is his heritage, may confidently leave the drudgery of routine determinations to the instruments of the physicist and the physical chemist.

* Attention might be drawn to the beautiful microtechnique of Price and Woods, which analyses as little as 0·004 cu. mm. of gas. See *Metallurgia*, 1945, **31**, 216.

9 *Metallurgia*, 1943, **28**, 303.
10 D. L. Masters, *Ibid.*, 1944, **30**, 169.

Microchemistry Group

THE next meeting of the Microchemistry Group of the Society of Public Analysts and Other Analytical Chemists is to be held in Manchester, on May 25, 1945.

Following a visit to the Microchemical Laboratories of the College of Technology from 2-15 to 3-15 p.m., a series of papers will be read at 3-40 p.m. in the Grand Hotel, Aytoun Street. The papers will comprise an opening address by the Chairman of the Group, Professor H. V. A. Briscoe ; Physicochemical Methods in Microanalysis, by Dr. Cecil L. Wilson ; The Determination of Trace Amounts of Sulphur Dioxide, with special reference to the Microdetermination of Sulphur in Ferro-alloys, by Mr. G. Ingram ; and Micro-Methods used in the Analysis of Cotton, by Miss M. Corner. This meeting is being held in conjunction with the local Branch of the Royal Institute of Chemistry.

Erratum

So much useful data is supplied in the advertisement pages of modern technical journals that the correction of errors, which may inadvertently appear, has become just as important as the correction of errors in the literary pages. Such an error occurred on page 31 of our April issue. On this page is given brief particulars of the copper base alloy known as " Kumium," produced by the Metals Division of the Imperial Chemical Industries, Ltd. In the range of properties for this material, in the form of rod, plate, sheet and sections, the elongation is given as 20–80% in 2 in., this should read 20–15% in 2 in.

Induction Heating

A Composite

THE wider acceptance and more general use of induction heating, during recent years, has placed equipment for this process in a large number of manufacturing and metal processing plants. The ready adaptation of this relatively new tool requires a knowledge of the various inherent characteristics and behaviour of high-frequency energy. The proper frequency, time cycles, and inductor design, and their relationship to the shape and dimensions of the metal part being treated are extremely important. Osborn[1] deals with a practical approach to the understanding and application of knowledge of such factors and dispenses with the more detailed and involved theoretical aspects.

This method of heating is applied to annealing, case-hardening, and to melting of steel and other metals. Although used more and more in all types of heat-treating operations, induction heating is by no means a universal form of heating, and does not replace or even provide a substitute for all types of fuel-fired furnace treatment. In the analysis of any heating problem there are three factors which will indicate from an engineering point of view whether heating by electric induction is applicable. The first of these factors is the localisation of heat to the surface of the metal in question, a phenomenon inherent in high-frequency induction heating by electric induction. The second factor is the localisation of heat to a specific longitudinal section of the metal article in question, this being controlled by exposing to the high-frequency magnetic field that section only which is to be heated. These two factors may both enter as in the case of surface hardening of a restricted section of a long shaft to produce a journal of good wearing characteristics and yet maintaining sufficient core toughness to prevent breakage under torsional stress. The third and last factor is that of rapid heating which is desired in order to prevent oxidation, scaling, and decarburisation, the magnitudes of which are all functions of time as well as temperature. Also into this third category fall problems where rapid heating is mandatory in order to overcome the inherent heat absorption inertia present with all forms of heating by thermal conduction or radiation.

Every annealing problem, according to Cable, should be approached in accordance with these three factors in order to determine whether or not induction heating is justified. As far as the first factor is concerned, very few, if any, problems will involve surface annealing with the possible exception of some threading or tapping jobs. The annealing of restricted areas longitudinally on a piece of steel, as defined in our second classification, is a common application of induction heating in industry. Designing a heating coil so that the section to be annealed is within the resultant magnetic field permits this area to be raised rapidly to the prescribed temperature, The energy input in kw./sq. in. is purposely kept low as compared with those values used for surface hardening. Typical values are from 2 kw./sq. in. (0·31 kw./cm.^{2}) down for annealing, while surface hardening figures run from 5 to 10 kw./sq. in. (0·77 to 1·5 kw./cm.^{2}) in the usual case, with exceptions as high as 100 kw./sq. in. (15·5 kw./cm^2). The reason for keeping this value low for annealing operations is to prevent appreciable temperature gradients across the metal piece which would result in non-uniform results. It should be remembered that all induction heating occurs at the surface of the metal, and the relative depth of penetration does not vary appreciably with the range of frequencies encountered in industrial use when thermal conduction is taken into consideration. Therefore, the degree of surface heating which is obtainable depends largely upon the amount of energy which is generated per unit of surface area.

Annealing operations falling into the final classification where rapid heating is desired, include the continuous heating of steel tubing, strip and wire to reduce the oxidation and overcome the time lag required to heat such sections in the conventional furnace. These applications usually involve other pieces of equipment such as rolling mills, drawing benches, or welding machines which handle the material at extremely high speeds, and consequently the pounds of material to be annealed per minute are correspondingly high. This rapid movement of the metal results in a conventional type heating furnace many feet in length to allow the metal to be in the hot atmosphere long enough to come up to temperature. When space is at a premium, this fact alone may indicate the use of induction heating.

Induction melting is as old as the application of induction heating. Large melting furnaces using relatively low frequencies are found in many steel mills, and there are a number of variations in design. It is believed that the more general interest in induction melting centres around the small crucible induction furnace which has a capacity of about 20 lb. This furnace has always been of interest due to its extreme flexibility for laboratory and small production use, and more so at present in conjunction with precision centrifugal casting which requires small-lot melting.

Much development work has been done in determining the correct type of crucible for induction melting applications, and the trend is definitely towards graphite crucibles, with or without ceramic liners, depending upon whether or not the melt will become contaminated by being in direct contact with the graphite at high temperatures.

Brief reference is made to the so-called "hyperhardness" obtained in induction hardened steels. Data has been verified many times showing that steels can be hardened to a Rockwell "C" reading of 2 to 7 points higher by high-frequency induction heating than by conventional means. An explanation has long been sought for this phenomenon and Cable suggests as one analysis of the problem: Hardness in steel has been shown to be a function of the solution and diffusion

1 H. B. Osborn, Jr., *Electrochem. Soc.*, 1944. Preprint, 86-18.

2 J. W. Cable, *Electrochem. Soc.*, 1944. Preprint 86-18.

of the iron carbide into and throughout the steel, the carbide being finely divided. Hence, any increase in hardness must be accomplished by a more complete solution and diffusion than that obtained by conventional heating methods.

Since the fundamental requirement of induction heating is alternating current, such heating can be accomplished with any frequency from the commercial 60 cycles up to millions of cycles per second. There are three recognised types of induction-heating equipment and there is a direct relation between the type of equipment, its practical frequency range, and the heating job it is best suited to perform. For the purpose of a brief review we can recognise the following:

First, motor generators are used for frequencies up to 12,000 cycles per second. These are well adapted to through heating or deep heating of ferro magnetic materials. This equipment is available up to thousands of kilowatts in output. Common sizes range up to 1,200 kw. The overall efficiency of the entire equipment is usually between 50/60%, while the efficiency of the frequency changer sets range from 80–90%.

Secondly, there are spark gap units for frequencies between 20,000 and 300,000 cycles per second. These are suitable for general heat-treatment such as melting, deep surface hardening and general purpose brazing. The power input of spark-gap equipments commonly ranges up to about 35 kw. The output varies widely, depending upon the type of load, the method of coupling and the condition of the spark gap. Under good conditions 50% efficiency may be realised whereas under poor conditions it may hardly exceed 15%.

The third and newest type of induction heating unit is the vacuum tube unit adaptable to frequencies from 350 kilocycles up to over 100,000,000 cycles per second. For induction heating purposes, frequencies between 350,000 cycles and 15,000,000 cycles are widely used. The power output of vacuum tube units reaches hundreds of kilowatts and common sizes range from 5–50 kw. output with the emphasis on 25/40 kw. sizes. The overall efficiency of vacuum tube equipment ranges between 50/60%, with a reliable operating efficiency of 50%.

In a recent paper by Sherman[3] thin case-hardening is discussed for which the induction-heating units are restricted to two types—*viz.*, the spark unit and the vacuum-tube unit. The phrase "thin case hardening" is defined as the surface hardening of cases in the order of 0·0001 in. (2·5 μ) thick on the surface of hardenable steel parts by the use of heat only and without scaling, warping or destruction of previous heat-treatment benefits developed in the metal just beneath the hardened surface.

The principal objections to spark-gap equipment arise from the fact that the power input of the device is always dependent upon the spark gap. Cleaning and adjustment of the spark gaps are required at intervals ranging from a few hours to a few days, depending upon the extent of use of the gaps. Variation of output power is satisfactory only where heating time is appreciable and human judgement can compensate for the output variation. The need for megacycle energy heating becomes evident with lightweight aircraft engine parts and many other manufactured items requiring precise and thin surface hardening with no hazard to the structure and properties of the underlying metal. Since the heat-treatment by this latter method is accomplished in one second or less, scaling is avoided even in ordinary atmosphere. The degree of tempering of the metal layer adjacent to the desired thin hardened case is a function of time and temperature. With lower frequencies the longer heating time allows the heat to penetrate too deeply into the core.

Cost of megacycle heat-treatment is in no way dependent upon the frequency used, but rather upon the efficiency of the frequency conversion means. Efficiency of conversion with vacuum tubes can be as high or higher than that of lower frequency sources. Depending upon the efficiency of the frequency converter, the heat-treating energy may cost from 1·5 to 3c/kw-hr. as compared with the base cost of 1c/kw-hr. for the commercial 60 cycle energy. The ultimate production costs are determined, however, by the degree of accuracy with which the heating energy is controlled. In one application, for example, an area of 50 sq. in. (323 cm.^{2}) was hardened to a depth of 0·020 in. (0·5 mm.) for each 1c worth of energy. The cost per square inch naturally increases with the depth of the case, and therefore for economy of operation it is desirable to restrict case depth to only slightly more than allowable wear of the part. Had it been necessary to heat the part mentioned to a depth of 0·2 in. (5 mm.) in order to obtain a case of 0·02 in. (0·5 mm.) the cost would have been multiplied by ten and 90% of the power wasted.

Practical applications of megacycle induction surface hardening have been made on various types of surfaces and on a number of types of steel. Flat surfaces with or without a closed loop of work have been successfully treated, demonstrating conclusively that no closed loop was necessary in order to get surface hardening with megacycle induction heating. Both types of flat surfaces were self-quenched after heating with megacycle energy for one second. When the power was cut off, the heated surface was instantly quenched by the cold mass of core material beneath it.

In another typical case both bearing surfaces of a certain partially hollow shaft were hardened to a depth of 0·020 in. (0·5 mm.) with a 1 sec. heat-treatment. The shaft was automatically tripped into a water quench at the end of the heating period and a hardness of 88 Rockwell 15 *N* or 55 Rockwell *C* was developed. The upper bearing of this shaft was treated in such a way that the hardened layer tapered away to zero, as it approached the spline, to avoid hardness in the spline teeth.

Tests performed to determine the relation between case depth and time of heat-treatment show this relation to be roughly linear to about one second for the power used. As the time was increased appreciably beyond one second, the slope of the case depth curve increased so rapidly that it became evident that accurate control of case depth proves very difficult after more than one second of exposure.

3 V. W. Sherman, *Electrochem. Soc.*, 1944. Preprint, 86-22.

Fatigue Properties of Some Cold-Drawn Nickel-Alloy Wires

By J. N. Kenyon

FATIGUE data were obtained on test specimens of nickel-alloy wire materials, cold-drawn to approximately 0·0375 in. in diameter and subjected to various thermal treatments. Fatigue tests were carried out with a rotating-wire arc fatigue machine in a highly neutral oil bath to 100 million cycles. All the materials, commercially processed, were tested in the processed condition with the

From *Proc. Amer. Soc. for Testing Materials*, 1943, Vol. 43, pp. 675–770.

usual run of surface irregularities. The data obtained, summarised in Table I, were obtained with fatigue failure occurring at any point within a 15 in. length, and should offer interesting comparison with those obtained with the standard rotating beam fatigue testing machine. In Table I are also reported modulus of elasticity values for the several alloys.

TABLE 1.—FATIGUE AND MODULUS OF ELASTICITY TESTS ON NICKEL ALLOY WIRES

Material	Treatment	Tensile Strength Tons/per sq. in.	Elon. % 2-in.	Modulus of Elasticity Lb. per sq. in.	Fatigue Limit Tons per sq. in.	Endurance Ratio
Nickel	Stress-equalised annealed at 300° C.	64·4	2·75	31,200,000	22·1	0·343
Monel metal	" " "	62·5	3·0	28,100,000	20·8	0·332
Inconel	" " " 425° C.	92·4	5·3	34,000,000	22·6	0·244
K Monel metal	" " " 300° C.	72·4	2·0	26,300,000	21·7	0·299
K Monel metal	Age-hardened at 540° C. for 8 hours and furnace-cooled	89·2	2·5	27,400,000	19·9	0·223
Iron-Nickel-Chromium Alloy	Stress-equalised annealed at 425° C.	67·5	3·5	30,100,000	20·3	0·302
Iron-Nickel-Chromium Alloy	" " " Age-hardened at 480° C. for 8 hours and furnace-cooled	89·7	3·0	33,200,000	21·9	0·244
Z Nickel		103·1	8·0	34,000,000	19·0	0·184

Short-Time Tests on Solders and Soldered Joints

By J. A. Kies and W. F. Roeser

MANY of the compositions of low-tin solders included in various specifications differ only in small percentages of elements, such as antimony, bismuth, copper and silver. Since short-time tests are frequently relied upon to prove the value or importance of such additions, it is essential to establish procedures which are simple and which will yield results, which are both reproducible and are easily interpreted. In the present work, the possibilities and merits of the scarf joint for test purposes were investigated, and tests of various solders were made with this and several other types of joints for the purpose of comparing the results obtained with different solders and different types of joints.

TABLE I.—COMPOSITION OF SOLDERS

Solder	Composition					
	Sn	Sb	Cu	Bi	Ag	Pb
50–50	—	—	—	—	—	—
B	40·0	0·30	0·06	0·20	—	remain
D	35·0	1·00	0·06	0·20	—	"
E	30·0	0·60	0·10	0·20	—	"
G	20·0	0·56	0·10	0·20	—	"
11	20·0	0·40	0·06	0·56	1·25	"
12	20·0	0·33	—	5·0	1·25	"
6A	15·0	0·33	—	—	—	"
13	15·0	0·33	—	0·06	1·25	"
14	15	0·33	—	0·50	1·25	"
15	9·97	0·33	—	0·06	1·50	"
EO6	2·99	0·33	—	—	2·24	"
16	—	6·33	—	—	2·49	"

Tests were made on 13 solders, Table I, 6 of which, Nos. 11, 12, 13, 14, 15 and 16, confirm in composition with A.S.T.M. specifications; 2 of which, 6A and EO6, are to S.A.E. specifications; 4 of which, B, D, E and G, are to Federal specifications and a commercial 50–50, lead-tin solder. Materials jointed were copper, brass and steel, and results are presented which indicate the effect of speed of pulling, rate of loading, time of supporting the load, temperature and pre-tinning on the shear strength of soldered joints.

Tests with different types of soldered joints in copper, brass and steel, led to the conclusion that in determining the relative shear strength of solders, there were certain marked advantages in using the scarf type of joint. These are that such can be machined and soldered easily, there is no bending during testing, the shearing area of the joint is definite and easily measured, fillets are practically non-existent, and the thickness of solder film can be easily controlled by inserting short pieces of fine wire for spacers. The results obtained with scarf joints were also consistent with those obtained with plug and sleeve joints and with butt joints in thin-walled tubes tested in torsion.

In tests to determine the rate of loading, speed of the moving crosshead, time held at maximum load and temperature on the shear strength of joints soldered with 70–30, lead-tin and 50–50 lead-tin solders, it was found that: (*a*) the maximum shear stress obtained doubled as the rate of loading was increased from 75 to 35,000 lb. per sq. in. per min.; (*b*) the maximum shear stress obtained was doubled as the speed of the crosshead was increased from 0·001 to 0·1 in. per min.; (*c*) the maximum shear stress more than doubled as the time of loading was decreased from 40 min. to practically zero; and (*d*) in the usual tensile test, the shear strength changed about 1% per deg. C.

There was very little difference in the shear strength of joints made with solders containing 15% or more tin. The fact that in short-time tests the shear strength of joints made with solders containing 10% or less tin was somewhat less than that of solders of higher tin content, should not be construed as meaning that the same would be true in long-time or creep tests, as available data represented that the reverse would be true. Small amounts of added elements such as bismuth, cadmium, copper, and silver, apparently have little effect on the shear strength of joints at room temperature.

In general, with the eutectic mixture of zinc and ammonium chlorides as a flux, the higher the tin content of the solder, the greater the amount of spreading on copper. With the same flux, the spreading on black iron was practically independent of the tin content for solders containing 10% or more tin. With one proprietary flux and silver-lead solder, however, approximately the same amount of spreading was obtained as was obtained with 50–50 lead-tin solder and the eutectic mixture of zinc and ammonium chlorides as a flux. The results of spreading tests indicated that there was little, if any, advantage to be gained by using soldering temperatures higher than 20° C. above the liquidus temperatures for the low-tin solders. Small additions of silver and bismuth together promoted appreciably greater spreading than that obtained with tin-solders of the same tin content.

Amer. Soc. for Testing Materials, 1944, June, Preprint No. 32, pp. 1–16.

Corrosion of Non-Ferrous Metals and Alloys

A REPORT of Sub-Committee V-1 of American Society for Testing Materials Committee B-3 is a continuation of the 1943 report of the same Sub-Committee, in which data were presented relating to tensile tests and weight loss determinations made on specimens of non-ferrous metals and alloys removed after approximately ten years' atmospheric exposure at various sites. Detailed information concerning test procedure, a summary of meterological data for the 10-year period, and particulars of the visual

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appearance of the materials after test were given in the 1943 report. The present report gives additional tensile test results and a summary of the conclusions which are considered to be justified on the basis of the data collected to date.

A series of tables has been compiled, bringing together in convenient and unified form, the results of the tests reported at various stages of the investigation, and giving particulars of calculations which have been deduced from the behaviour of the respective materials. The summary data now presented are shown in the form of "graded summaries." In these tables, the changes in the materials, such as loss in weight, average penetration, changes in tensile strength, etc., have been arranged or graded in the order of the material showing the least amount to the material showing the greatest amount at each of the test sites. The data on the exposed specimens are correlated with the relevant data on the materials in their original condition and with the properties of specimens which have been tested under protected conditions over the 10-year period. The materials over which data are tabulated include commercial copper, commercial tin, commercial nickel, commercial zinc, tin bronze, aluminium bronze, manganese bronze, brass, copper-nickel-zinc alloy, copper-nickel-tin alloy, Monel metal, duralumin, aluminium-magnesium-silicon alloy, lead-antimony alloy and chemical lead.

While a careful study of these graded summary tables might permit certain general conclusions to be drawn as to the relative corrosion resistance of the various metals and alloys in the different types of atmospheres, it is the Committee's opinion that a better survey and a more accurate statement of the test value of the data collected to date can be made by individuals most familiar with the corrosion performance of the particular metals and alloys. The Committee, therefore, proposes to sponser a series of papers in which the corrosion performance of materials included in this investigation can be discussed more freely and more fully than would be possible by the Committee acting as a whole. Arrangements have therefore been made to have individuals present papers covering the following: (*a*) Copper and copper alloys; (*b*) zinc materials; (*c*) nickel and nickel alloys; (*d*) aluminium and aluminium alloys; (*e*) lead and lead alloys and tin. Another paper will deal with the significance of changes in storage specimens and discrepancies between data on loss in tensile strength and loss in weight.

Melting and Evaporating Metals in a Vacuum

By W. J. Kroll

THE recently introduced process for producing magnesium by the reduction of dolomite in a vacuum has brought considerable interest in vacuum metallurgy. The knowledge acquired in this development can in general be applied to the melting and distilling of metals and alloys with the intention of purifying them or to improve their properties or to produce sounder castings. Experiments in this direction may be a complete failure if the phenomena observed in melting and evaporating metals in a vacuum are not taken into careful consideration.

Factors involved in the melting and evaporation of metals at reduced pressures, and resulting lower temperatures, are discussed. The effects of hydrostatic pressure, metal-vapour pressure, and of residual-gas pressure are shown to be very important. When the use of vacuum in metallurgy is proposed, an accurate specification of pressure and temperature to be used is necessary. There is no method available for the determination of the real pressure—*i.e.*, the total pressure existing at the molten metal bath level, since the partial pressure of the metal vapour cannot be determined. While the total pressure at the metal surface is always pretty close to that of the metal vapour during actual distilling and the residual gas pressure (air, etc.), is relatively low, the reverse is the case when melting metals. We generally melt the less volatile metals in a vacuum at a pressure of between 1 mm. and 10 mm. Hg, measured at the furnace shell. The vapour pressure of the metal is relatively negligible in this case. We would encounter complete failure, due to large metal losses during vaporisation, if we were to attempt to use the best possible vacuum for melting. Some metals, like magnesium and chromium, cannot be melted in a good vacuum in an open crucible.

When a poor vacuum is used for melting, it is found to be quite effective for degassing the metals. The use of a good vacuum for annealing operations may sometimes prove to be a failure where a relatively volatile metal constituent is present. Thus brass cannot be annealed in a good vacuum without appreciable zinc losses. Nor can iron sheet be annealed at high temperature, at low pressure, without losing manganese. "Alpax" aluminium-silicon alloy loses its sodium upon remelting in a vacuum. Analytical methods have been based on these observations. It is evident therefore, that the furnace pressure has to be adjusted to the task in question. It has to be as low as possible for distilling in vacuum; and fairly high (between 1 and 10 mm. Hg, depending upon the metal involved) for melting in vacuum.

Evaporation of solid metals in a high vacuum is largely influenced by the state of the surface. Every metal surface is supposed to be covered by an adsorbed gas layer which can be removed by heating to 400°–500° C. in a good vacuum. Besides this, there is a chemical layer of metal oxide or nitride or the like on the metal surface which acts as a strong barrier that has to be broken down before the metal vapour can escape. Therefore, the gas builds up under this oxide film until a break-through occurs. The strength of such oxide films can be seen from the residues obtained when subliming magnesium. As soon as the chemical layer is removed, either mechanically or by dissociation, the true evaporation starts. However, residual gas may react with the metal surface and provide it with a new skin. The role of the residual gas, therefore, becomes preponderant in a high vacuum. Dissolved gases in the metal will escape but will require many hours of pumping since they diffuse slowly from the centre. As soon as the metal surface is in the right condition for true evaporation, a gas cloud forms over the metal. Atoms escape into the surrounding space, while others drop back from the cloud and condense on the metal surface. With varying pressure, the cloud may frequently expand in the space or it may collapse back on to the metal surface. This leads to a roughening of the surface. Furthermore, preferential evaporation may take place at the grain boundaries

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where volatile impurities may concentrate. Pitting and local corrosion, as observed during the subliming of magnesium, may appear and a typical vacuum structure may develop.

Alloys in a Vacuum.—What is to be expected from vacuum methods for the purification of impure metals and alloys ? The lower temperature, as compared with the operation at atmospheric pressure, means saving in fuel and in refractories, which last longer. Furthermore, a more efficient purification is possible.

The use of a vacuum to separate metals has not yet found practical applications except for purifying mercury. The recovery of magnesium from scrap may play a role after the war. The elimination of Bi contained in copper has been suggested. Brass separation into copper and zinc has been tried on a small scale in Germany. The separation of tin-lead has likewise been proposed. It is possible to shift the tin-lead ratio at low cost, even though traces of lead may be difficult to remove. The prospects for vacuum purification of zinc are very good since it can be performed at a temperature slightly above 500° C. which allows for a greater choice of materials of construction than those available in the present retort practice.

Sulphides are generally weak compounds. Molybdenum sulphide can be broken up into metal and sulphur by heating in vacuum. This makes it hopeful for vacuum treatment of matte and speiss. The possibility of separating lead from noble metals and eliminating cupelling might also be considered. In the bismuth and antimony industry uses may be found for vacuum metallurgy.

Vacuum degassing has been practised on a fairly large scale in the case of steel, nickel, and nichrome. High-frequency vacuum furnaces are suitable for this operation. It is claimed that metals thus treated possess outstanding properties. Vacuum-degassed metals are used in radio tubes.

Tinning Cast Iron for Bearings

By T. E. Eagan

A COMPARATIVELY recent process for preparation of metal surfaces, the Kolene process, has made possible the cheap, quick and dependable tinning of cast iron. The cast iron, once tinned, can be used as a base for a thin layer of white metal that will be bonded over the entire area of contact, and so satisfactory has this bonding proved in service that high strength cast iron bearings are now being used, without any anchor grooves, for heavy duty in Diesel engines.

The difficulty in tinning cast iron has been that the graphitic carbon, inherent in the metal, spreads out over any machined surface and prevents bonding. In the new process, graphitic carbon is oxidised at the surface of the metal, and the oxides of iron formed simultaneously are afterwards dissolved away without exposing more graphite flakes. Graphite itself is oxidised to carbon dioxide, which combines with the alkaline constituents of the bath in which the work is immersed, forming carbonates. The surface of the cast iron is thus left chemically clean with perhaps a very thin layer of ferrite, to which the tinning metal readily reacts to form a bond.

In operation, the first step is immersion in a molten salt bath, alkaline in reaction, containing a catalytic agent to promote oxidation. This bath is operated at 700°–950° F., but preferably above 800° F. for graphite removal. Time of immersion may be from 5–30 min., depending on the type of material to be cleaned. Upon removal from the oxidising bath, the work is rinsed in water, then put back into a second bath, also alkaline in nature, when metallic oxides are dissolved away without attack upon the metal itself. The second bath, a water solution of active agents operates at about 250° F., or just below its boiling point, and immersion in this bath should be twice the length of time the work was held in the first bath. After immersion in the second bath, a water rinse follows, then an immersion for 20–60 secs. in 20–30% hydrochloric acid to neutralise any remaining alkali, then a flux bath after which the work goes directly into the molten tinning metal where a few moments of swirling suffice to heat it to bath temperature, after which it is removed completely tinned.

This cleaning process has made possible the substitution of centrifugally cast white metal cast iron bearings for steel-backed bearings. In addition to preparing cast iron for successful tinning, the Kolene process cleans other metals which are ordinarily tinned with difficulty. Manganese bronze, in which manganese oxide makes bonding uncertain, can be prepared adequately, the oxides being dissolved in the second bath. Silicon bronze, regarded as impossible to tin properly, causes no trouble, while silicon steel, which is sometimes soldered for transformer applications, can be prepared without difficulty. The process is not applicable to aluminium and magnesium alloys.

Metals and Alloys, 1944, vol. 20, No. 3, pp. 625–629.

Nickel-Bronze Castings

By E. Portman

DETAILS are presented of a substitute alloy for gunmetal and silicon bronze, having a tensile strength of approximately 20 tons/sq. in. This alloy contains 87% copper, 4% tin, 4% nickel, 4% zinc and 1% lead, and is melted in a high frequency coreless induction furnace. An oxidising atmosphere must be maintained during melting and deoxidation is accomplished using 10% phosphor copper. Using such melting practice, standard test bars give physical properties shown in Table I.

TABLE I.—PHYSICAL PROPERTIES OF NICKEL BRONZE

	Range	Average
Tensile strength .. .. Tons/sq. in.	18·0–24·0	20·0
Yield stress .. .. Tons/sq. in.	8·0–10·0	8·4
Elongation—2 in. ..	22–44%	34·6%
Brinell hardness (500 kc)	53–74	60
Specific gravity	8·53–8·77	8·67

In foundry practice, sprues and gates should be somewhat larger than for gunmetal, and risers should be the same as for gunmetal and smaller than for silicon bronze. The proper pouring range is 1,125°–1,200° C., and gates, sprues, and runners must be adjusted to filling the mould quickly, yet without turbulence, as the freezing range of the alloy is short. A liberal use of chills in heavier sections of a casting that cannot be fed by risers is recommended.

X-ray examination of several castings has shown complete freedom from shrinkage porosity and pressure tests of these castings after machining have resulted in less than 1% rejections due to porosity.

Metals and Alloys, 1944, vol. 22, No. 3, pp. 620–624.

Effect of Temperature on the Properties of Metals

TWO reports issued by the Joint Research Committee of the American Society of Mechanical Engineers and the American Society for Testing Materials deal with the effect of temperature on the properties of metals. The first considers the effect of variables on the creep resistance of steels and the second, a correlation of short- and long-time elevated temperature test methods.

In the first report H. C. Cross and W. Simmons give the results of creep tests at 455° C. (850° F.) on two silicon-killed steels, a silicon-aluminium-killed steel, an aluminium-killed non-ageing steel, a rimmed carbon-molybdenum steel, and on plain carbon and carbon-molybdenum weld metal. All the materials except the weld metal were heat-treated to produce fine and coarse-grain structures for comparison of their relative creep resistance and to determine the effect of deoxidation practices.

The creep resistance, 455° C., of a silicon-killed steel, containing 0·14% carbon, 0·48% manganese, was not changed much by a change in austenitic grain or cooling rate from the coarsening temperature. The silicon-aluminium-killed steel, 0·17% carbon, 0·48% manganese, which showed poor creep resistance in the fine-grain condition, was greatly improved by coarsening and air cooling, and showed intermediate creep resistance as a result of slower and controlled cooling rates after coarsening. Both steels showed creep resistance approaching that for fine-grain material when they had a short-time grain refining treatment subsequent to a previous coarsening treatment. Room temperature tensile impact properties previously found for fine-grain material were practically duplicated. A moderate improvement in creep resistance at 455° C. was obtained upon coarsening and air-cooling a British silicon-killed steel, containing 0·16% carbon, 0·08% manganese and this together with the poor creep resistance in the fine-grain condition, suggested that 0·09% silicon might be too low to provide the silicon-containing inclusions postulated to provide good creep resistance.

Coarsening followed by air-cooling of the aluminium-killed non-ageing steel produced some improvement in the creep resistance at 455° C., but not so much as was expected. This steel, with a higher aluminium addition than 2·8 lb. of aluminium per ton, required water quenching from the coarsening temperature to produce the low creep rate obtained by air cooling steels with lower aluminium additions. Molybdenum added to rimmed steel improved the creep resistance at 455° C., as well as when added to killed steels. Only a slight improvement in creep resistance resulted from coarsening. The presence of molybdenum in rimmed steel appeared to offset in part the previous large effects on creep resistance owing to differences in deoxidation practice shown by plain carbon steels.

Plain carbon and carbon-molybdenum weld metal, even though extremely fine-grain, showed excellent creep resistance at 455° and 510° C. The rapid cooling that takes place during welding, while producing an extremely fine grain, probably also produces a near optimum size and dispersion of inclusions or carbides and hence a good creep resistance.

In general the experiments showed that creep resistance is probably determined by the size, mode and degree of dispersion of inclusions of various types and compositions. Deoxidation practice and heat-treatment, and particularly the temperature of heat-treatment (as indicated by the austenitic grain size) were important factors in influencing creep. Differences in creep resistance shown could not be predicted from either structures or room temperature tensile properties.

In the second report results are given of an investigation made of ten types of short-time creep at temperatures up to 540° C. These included hot-hardness, standard short-time tension, constant strain rate tension, sustained-load tension, stress-rupture, Hadfield time yield, DIN (DVM), Barr and Bardgett, step-down relaxation (flow rate), and constant-strain relaxation tests. A plain carbon steel, 0·35% carbon, 0·55% manganese and a carbon-molybdenum steel, 0·16% carbon, 0·66% manganese, 0·53% molybdenum in the form of bars heat-treated to obtain a high degree of uniformity and stability of properties, were distributed among various co-operating laboratories having high-temperature testing equipment. Tests on the plain carbon steel were confined to 455° C., while the carbon-molybdenum steel was studied at both 455° and 540° C. Long-time creep tests were also made on both steels.

Examination of the data obtained from the various tests showed that from a quantitative standpoint, the tests were not able to predict long-time (creep) strength accurately and consistently. To do so it is necessary that a short-time test result should be either the creep strength or some value which can be used to predict the creep strength, or the ability to predict and allow for any metallurgical change which may occur during long-time service and thereby change the creep strength. It was considered possible that some of the tests considered could be developed to predict creep strengths, provided that the materials remained essentially unchanged by strain-hardening or structural changes during long-time exposures to stress and temperature. The fact that most materials do not remain stable is a limiting factor on even the standard 1,000-hour creep test.

The tests considered in the investigation have been grouped into the following types: (1) Empirical tests that, on the basis of more or less long-time tests, measure some value of the material that may be related to the creep strength, and which include hot hardness, short-time tension, constant strain-rate tension, stress-rupture, Barr and Bardgett, and the various relaxation tests. Such tests fail to predict long-time behaviour accurately and consistently because they either over-stress the material, measure a quantity which bears no relation to the creep strength, or fail to take into consideration possible metallurgical changes; (2) tests which measure some early portion of the standard creep curve and which include the Hatfield time-yield and the DIN (DVM) tests. Such methods may be reliable provided the material is stable at the temperature of test; (3) short-time creep tests which include the sustained load-tension test and the step-down relaxation (flow rate) test. The best correlations between long-time and short-time tests were obtained for the tests which measured actual creep rates. These include the sustained load-tensile test, the Hatfield time-yield test and the DIN (DVM) test. These tests showed the most promise as short-time tests for predicting long-time behaviour, but should not be applied to materials which will be unstable under long-time conditions without further confirmation.

Amer. Soc. for Testing Materials, 1944, June. Preprint No. 25, 56 pages).

Heat Treatable Nickel Alloys

By W. J. Kroll

BERYLLIUM-NICKEL alloys are age-hardening to a very considerable degree. In an attempt to substitute beryllium partly or totally with other elements, magnesium was introduced into nickel in increasing amount. Beryllium free magnesium-nickel alloys made from Mond nickel did not show any signs of ageing, but similar alloys made with rolled nickel hardened very considerably. Although the impurities in the rolled nickel were considered normal, the presence of fairly large amounts of carbon and magnesium suggested those elements as a cause of hardening. Two series of alloy were therefore made from Mond nickel which contained 0·05% carbon and increasing amounts of carbon and magnesium alternatively. A series of alloys, containing both carbon and magnesium was also prepared.

TABLE I.—NICKEL ALLOYS. QUENCHED FROM 1,050° C. AND ANNEALED AT 500° C. FOR 20 HOURS

No.	C %	Mg %	Malleability	Hardenability	Quench hardness	Hardness as aged
NICKEL-CARBON ALLOYS FREE OF MAGNESIUM						
1	0·60	—	Good	No ageing	—	—
2	1·52	—	,,	,,	—	—
3	2·01	—	,,	,,	—	—
4	2·18	—	,,	,,	—	—
NICKEL-MAGNESIUM ALLOYS FREE OF CARBON						
1	—	0·39	Good	No ageing	—	—
2	—	0·70	,,	,,	—	—
3	—	0·85	,,	,,	—	—
4	—	0·94	,,	,,	—	—
5	—	1·10	,,	,,	—	—
6	—	1·36	Bad	,,	—	—
7	—	1·80	Not malleable	,,	—	—
NICKEL-MAGNESIUM-CARBON ALLOYS						
1	0·24	0·50	Good	—	120	190
2	0·22	0·91	Fair	—	174	401
3	0·24	0·88	Good	—	156	363
4	0·27	1·10	Difficult	—	156	363
5	0·27	0·94	Good	—	152	415
6	0·19	1·12	Fair	—	159	388
7	0·26	0·65	Good	—	131	197

The alloys were melted in small high frequency furnaces in alundum crucibles and the last traces of carbon eliminated by oxidation before adding the other elements. Carbon was introduced as a 2·2% carbon-nickel alloy and magnesium as a 30% alloy. The ingots obtained were about 1½ in. square and were rolled to about ⅝ in. square to determine the hardness (500 kg. load, 10 mm. ball, 1 min.) or to wire and sheet to determine the mechanical properties. The various alloys were quenched from 1,050° C. and annealed at 500° C. in a gas-fired furnace which permitted operations in the absence of oxygen. Results obtained from the three series of alloys are given in Table I and show that while alloy of the carbon or magnesium series does not age-harden, alloys containing both elements give good results.

Nickel-carbon alloys with up to 2·19% carbon could not readily be rolled while nickel-magnesium alloys with 1·1% magnesium were still malleable. Alloys containing both carbon and magnesium were found to be less malleable, as it was found that the alloy composition had a considerable influence on the malleability. High-carbon contents embrittle, if much magnesium is present. Nucleus forming agents like titanium, which produced titanium carbide, improved the malleability slightly by controlling the transcrystallisation, as did annealing at 1,100° C. for at least six hours. After the as-cast structure had been broken down, no more difficulties were found in the rolling even of high alloyed compositions.

TABLE 2.—HARDNESS AS A FUNCTION OF MAGNESIUM AND CARBON QUENCHED FROM 1,100° C. AND ANNEALED AT 500° C. FOR 24 HOURS

Mg %	C. % 0.07	0.10	0.15	0.20	0.30	0.40	0.60	0.90
0.0	100	104	108	110	120	125	125	130
0.1	110	130	160	200	210	250	—	—
0.2	120	150	210	270	270	270	250	—
0.3	135	190	260	330	330	—	—	—
0.4	145	230	310	350	340	340	—	—
0.5	160	270	320	360	360	340	375	—
0.6	185	295	330	370	375	405	—	—
0.7	220	305	330	370	375	—	—	—
0.8	245	310	330	370	380	400	465	—
0.9	270	315	330	370	380	400	—	—
1.0	280	320	335	370	360	390	390	—
1.1	—	—	—	340	330	—	—	—

Carbon and magnesium affect the maximum hardness obtained after ageing. This is shown in Table 2, where the hardness is given as a function of magnesium and carbon content. A maximum hardness of 405 was obtained with an alloy containing 0·4% carbon, and 0·6% magnesium, and with 0·2–0·3% carbon and 0·3–0·4% magnesium a hardness of 330–350 was obtainable. Although none of the nickel-magnesium-carbon alloys reached the high hardness values of nickel-beryllium alloy (550–600 with 2·5% beryllium), nickel-magnesium-carbon alloys find considerable use as materials for springs. Since the combination of carbon and magnesium caused ageing, it was considered that other elements might be substituted for any one of these constituents. Experiments with boron, titanium, copper, silicon, tin, zinc, aluminium, iron, tungsten, chromium, and cobalt showed that no substitute for magnesium could be found nor could carbon be efficiently replaced. A weak ageing was found with carbon-calcium and carbon-silicon combinations, and silicon produced ageing if considerable amounts were used.

As regards the cause of age-hardening in these alloys, no definite explanation is given. Whether carbon reduces the solubility of $Mg\ Ni_2$ in nickel, or whether this compound reduces the solubility of carbon has not yet been shown. It was noted, however, that even very small amounts of carbon produced ageing, if sufficient magnesium was present. As for almost all age-hardening alloys, the tensile strength was found to increase considerably and the elongation to fall in all the aged alloys. For an alloy containing 0·68% magnesium, 0·16% carbon, a tensile strength of 45 tons per sq. in. and an elongation of 38·2% with a Brinell hardness of 125 was obtained after quenching from 1,100° C. which properties increased to 90 tons per sq. in., 3·3% elongation and 330 Brinell hardness after annealing 20 hours at 500° C.

From *Metals and Alloys*, 1944, Vol. 20, No. 6, pp. 1604-1606.

The Atmospheric Corrosion of Copper

By A. W. Tracey, D. H. Thompson, and J. R. Freeman

DATA are given on an investigation of the corrosion of several brands of copper in the form of sheet and wire exposed to industrial, marine and rural atmospheres over several periods up to 10 years. The brands of copper available for the tests included electrolytic copper, N.E.C. and Chile; prime lake copper, Tamarack; arsenical lake copper, Tamarack and Superior, and special arsenical electrolytic copper; silver-bearing lake copper, Franklin and special silver-bearing electrolytic copper, fire-refined Wallaroo and A.B.S. copper; and phosphorus-deoxidised electrolytic copper in the form of cold-rolled and annealed sheet metal 0·050 in. thick or in the form of hard-drawn wires ⅛ in. in diameter or both. Sheet metal specimens were also exposed to sea water corrosion at half tide for three periods up to two years.

The amount of corrosion was determined on the sheet-metal specimens by changes in weight, tensile strength

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and elongation and on wire specimens by changes in tensile strength, elongation and electrical resistance. The significance of the weight change data was determined by statistical analyses. The measurement of changes in tensile properties on sheet metal and wire specimens exposed to the several atmospheres was not delicate enough to detect differences in corrosion rates among the various types of copper. The determination of changes in electrical conductivity of copper wire specimens to detect differences in amounts of corrosion gave results which were significant, yet the agreement with loss in weight determinations was poor in many cases.

The weight change data indicated that in industrial and marine atmospheres high-purity electrolytic copper and fire-refined Wallaroo copper (the latter with 0·25% of nickel) were more corrosion resistant than the general average and the arsenical lake coppers were somewhat less corrosion resistant than the average. There did not appear to be any significant differences in corrosion resistance among the following types of copper: prime lake, silver-bearing lake, phosphorus-deoxidised electrolytic, fire-refined A.B.S., silver-bearing electrolytic, or arsenical electrolytic. There was some indication that the arsenical lake coppers were corroded more uniformly than the other coppers in industrial atmospheres.

In rural atmosphere, pure electrolytic, prime lake, silver-bearing lake and phosphorus-deoxidised electrolytic copper were corroded significantly more than the average, arsenical lake and arsenical electrolytic were corroded significantly less than the average, and there was no significant differences among fire-refined Walleroo, fire-refined A.B.S., and silver-bearing electrolytic copper. The effect of corrosion on electrolytic resistance confirmed, in general, the weight-loss results at the rural location. The arsenical coppers were significantly more resistant to clean sea water than the other coppers tested, as confirmed by both weight changes and changes in tensile strength.

In general, the differences in resistance to atmospheric corrosion of the several types of copper tested were small in magnitude and probably had little, if any, practical significance in normal service.

Substitute Solders of the 15—85 Tin-Lead Type

By J. B. Russell and J. O. Mack

IN an investigation to develop an alloy containing a maximum of 15% tin, with no cadmium or bismuth, having soldering properties equivalent to or better than those of substitute solders specified to contain 18–20% tin or even approaching the properties of the standard 40–60 tin-lead solder, eleven elements were used in various combinations with the basic 15–85 tin-lead alloy. These elements were antimony, silver, copper, indium, thallium, lithium, calcium, barium, potassium, sodium and arsenic. In all, 116 low-tin solders were tested so as to give a solder with satisfactory working properties, specifically in regard to "wetting" of copper, brass and iron, solidification range, capillarity and shear strength of a soldered joint.

The "spread of a drop" test was used as a measure of wettability of a solder on base metal. Tests were of 15 secs. duration and were made at 60° C. above the liquid of the alloy being tested, using solder pellets having a constant volume of 0·025 c.c. The relative capillarity of the solders was determined by measuring the rise of an alloy column in a hole of 0·04 in. diameter drilled in copper, and for an accurate determination of the rise, specimens were radiographed by means of X-rays and measurements were made on the negative, using dividers and a steel rule calibrated to 1/100 in. The shear strength of soldered joints was determined, using the brass ring-and-plug type of specimen, and tinning qualities were determined mainly by the readiness with which the solder adhered to a clean iron. Of the alloys investigated, the nine alloys which passed the property requirements are given in Table I.

Of the added elements available, antimony was the only one that had an appreciable effect on the solidification range. No other element or group of elements was found to be very effective in reducing the liquidus temperature. In order to maintain satisfactory wettability, such as that required by a general purpose solder, less than 1·2% of antimony must be used and this amount will not give a solidification range comparable with that of a high tin solder. The addition of silver, alone or with other elements, was limited to 2% because of the formation of excess Ag_3Sn compound and the use of indium on account of its high cost was limited to 1%. Of the remaining added elements investigated—copper, thallium, sodium, calcium, lithium, potassium, barium and arsenic—none was found to improve to a satisfactory extent the wettability of a 15% tin alloy containing antimony.

As a result of this investigation, 15% tin solders, having a solidification range comparable with or slightly above that of an 18–20% tin substitute solder, have been developed. The composition ranges of this group of solders, as ascertained from the experimental data, are given in Table II. These solders, especially 1 and 3, were found to be very good substitutes for the 20% tin solder and adequate substitutes in some respects for the 40–60 tin-lead solder.

TABLE I.—Comparison of the Properties of Substitute Solders

Alloy No.	Composition					Solidification range °C.	Wetting sq. in.			Capil. rise in.	Shear strength lb./sq.in.	Tinking property
	Sn	Cu	Ag	In	Sb		Cu	Brass	Fe			
8	14·2	0·2	—	—	—	106	0·195	0·08	—	0·47	4,130	V.G.
20	14·2	0·10	2·00	—	—	103	0·21	0·155	0·38	0·575	3,760	V.G.
21	14·0	0·37	2·03	—	—	99	0·20	0·13	0·37	0·53	3,800	G.
30	14·3	—	2·02	0·75	—	102	0·28	—	—	0·46	3,430	G.
31	14·3	—	2·06	1·30	—	103	0·29	0·12	0·30	0·49	3,620	G
40	14·74	—	2·06	0·25	—	103	0·20	—	—	0·51	3,440	G.
41	14·82	—	2·02	0·54	—	99	0·28	—	—	0·46	3,620	G.
42	14·50	0·18	2·05	0·34	—	102	0·30	—	—	0·49	3,710	G.
49	15·10	—	2·04	—	0·96	91	0·22	—	—	0·47	3,830	G.

V.G. = Very Good. G. = Good.

TABLE II.—Recommended Composition Ranges for Substitute Solder of 15% Tin Class

Solder	Tin	Silver	Indium	Antimony	Copper	Lead
1	14·5–15·5	1·7–2·0	0·3–0·5	—	0·15–0·25	Balance
2	14·5–15·5	1·6–2·0	0·5–1·0	—	—	,,
3	14·5–15·5	1·7–2·0	—	0·8–1·2	—	,,
4	14·5–15·5	1·7–2·0	—	—	0·1–0·35	,,
5	14·5–15·5	—	—	—	0·15–0·25	,,

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